March 1996 Vol. 20 No. 3

NASA Tech Briefs

The Design/Engineering Technology Digest

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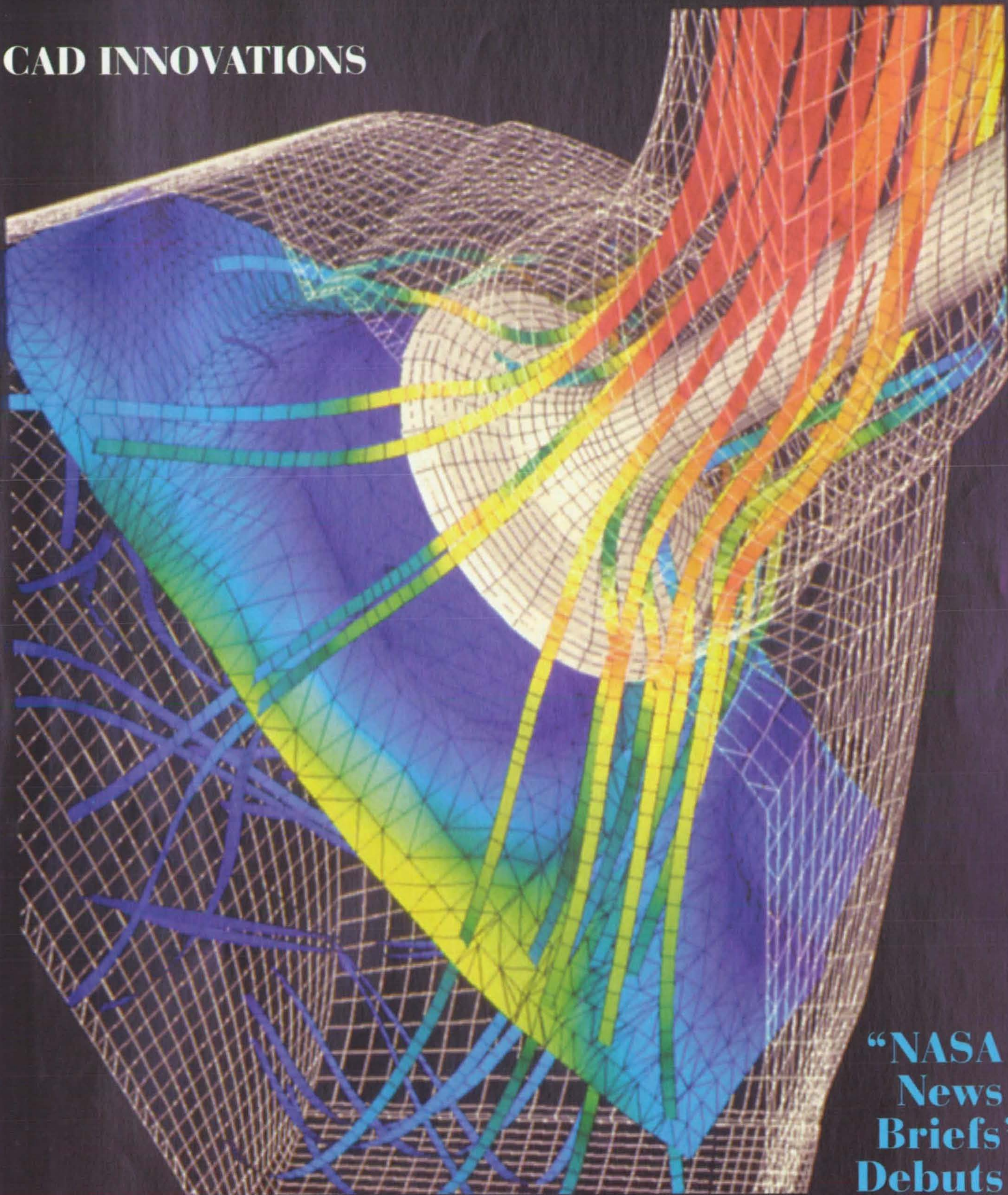

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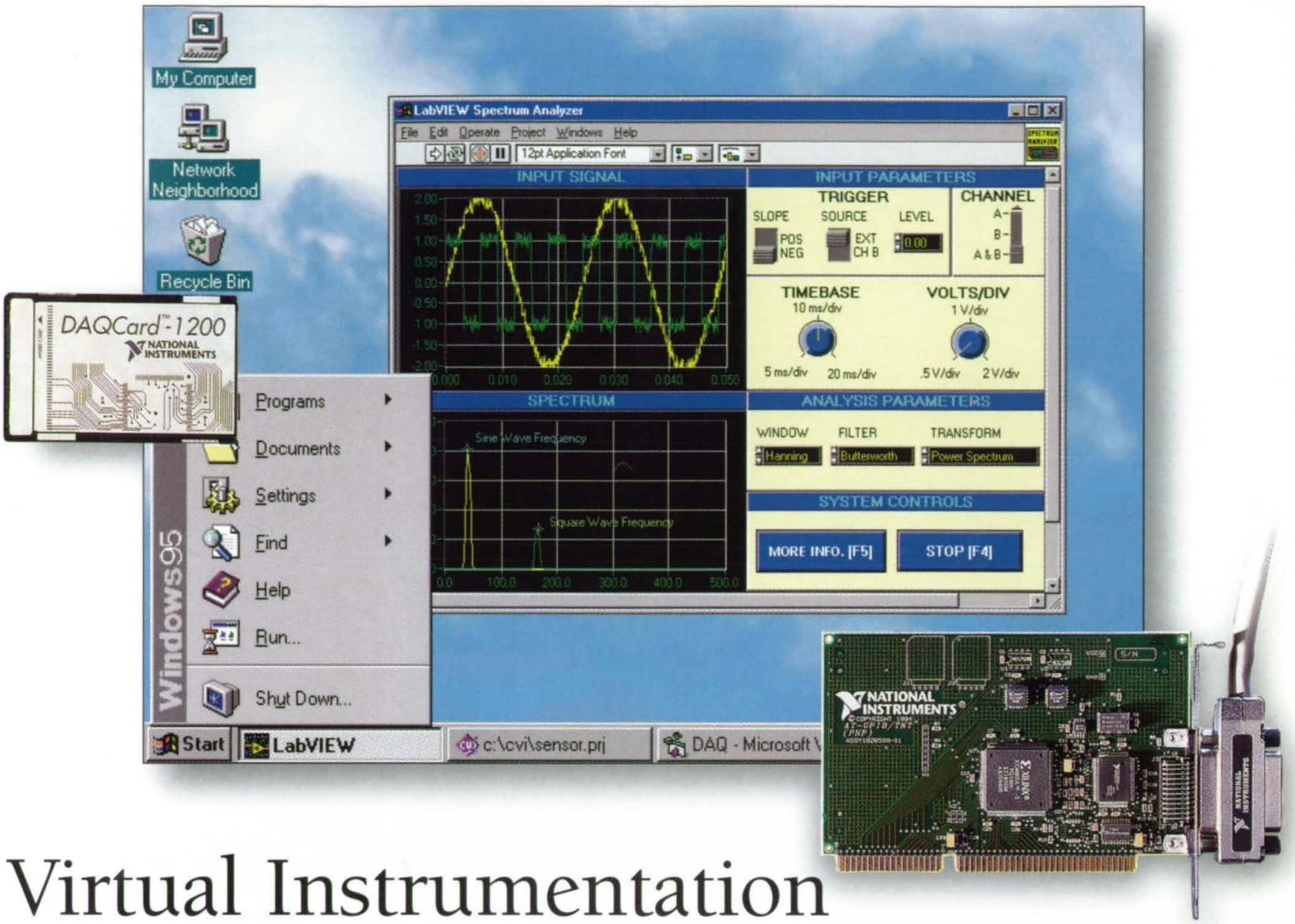
Compatibility from the Start



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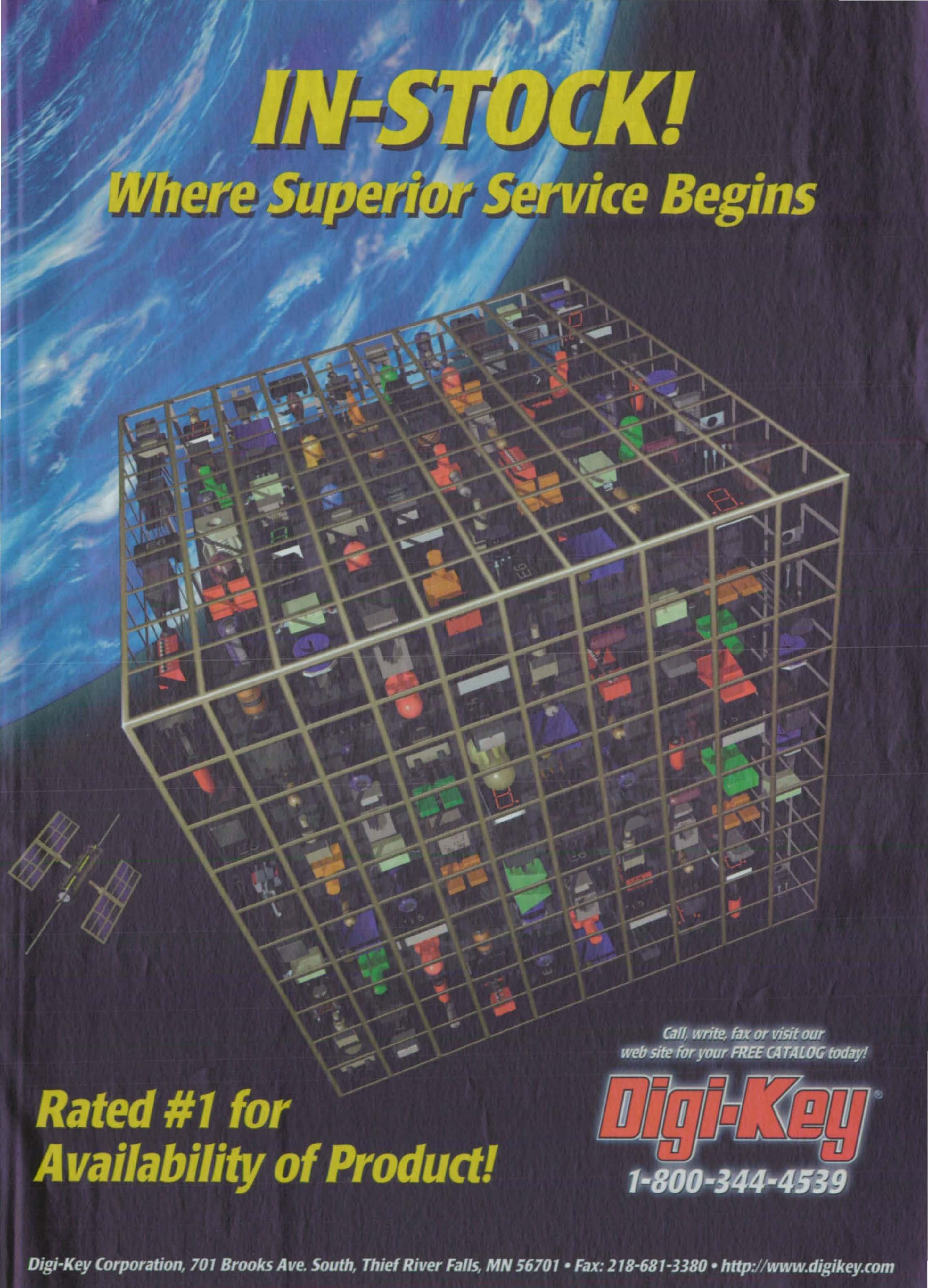

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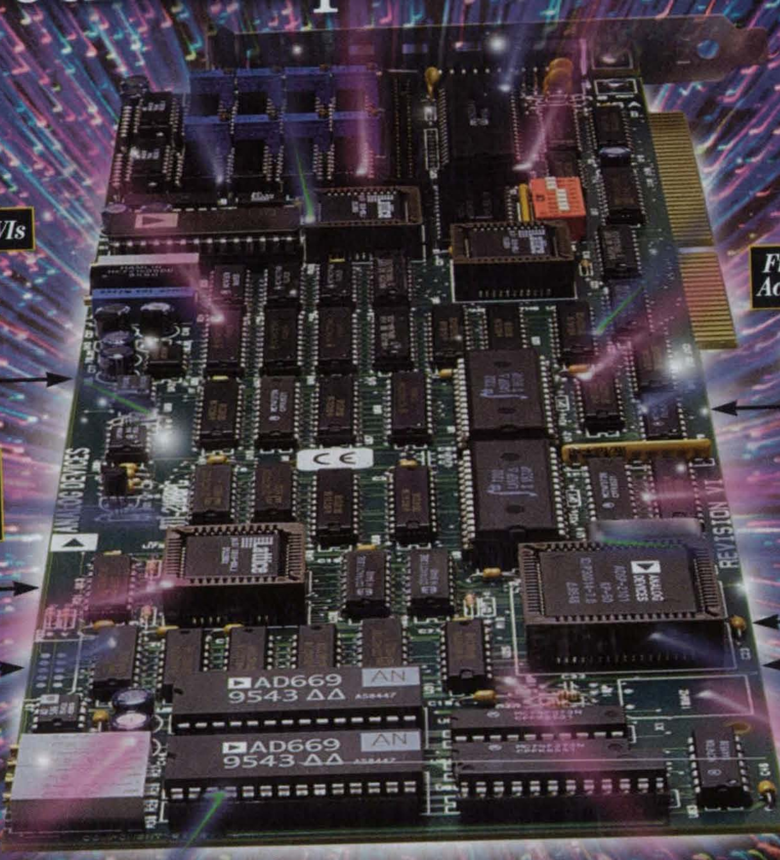

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TECHNICAL SECTION

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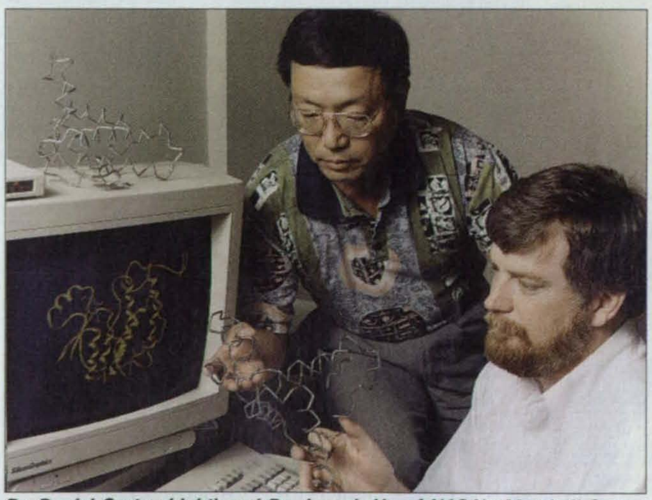

Dr. Daniel Carter (right) and Dr. Joseph Ho of NASA's Marshall Space Flight Center examine a three-dimensional mockup and computer simulation of the atomic structure of an important enzyme from a parasite known to cause schistosomiasis, the second leading cause of death worldwide. The discovery may lead to combining drug treatment and preventive vaccines to stop transmission of the disease. For more information on this breakthrough and other NASA developments, see "NASA NewsBriefs," which premieres this month on page 18.

Photo by Emmett L. Given, courtesy of Marshall Space Flight Center.

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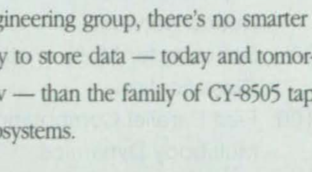

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Contents *(continued)*

On the cover:
Colors represent velocity in this transient simulation of an input valve performed by Ford Motor Company using STAR-CD. EnSight, a postprocessor from Computational Engineering International of Research Triangle Park, NC, was used to visualize and animate the results. For more information on advances in computer-aided design and engineering, see the Special Focus beginning on page 22.

Photo courtesy of Computational Engineering International

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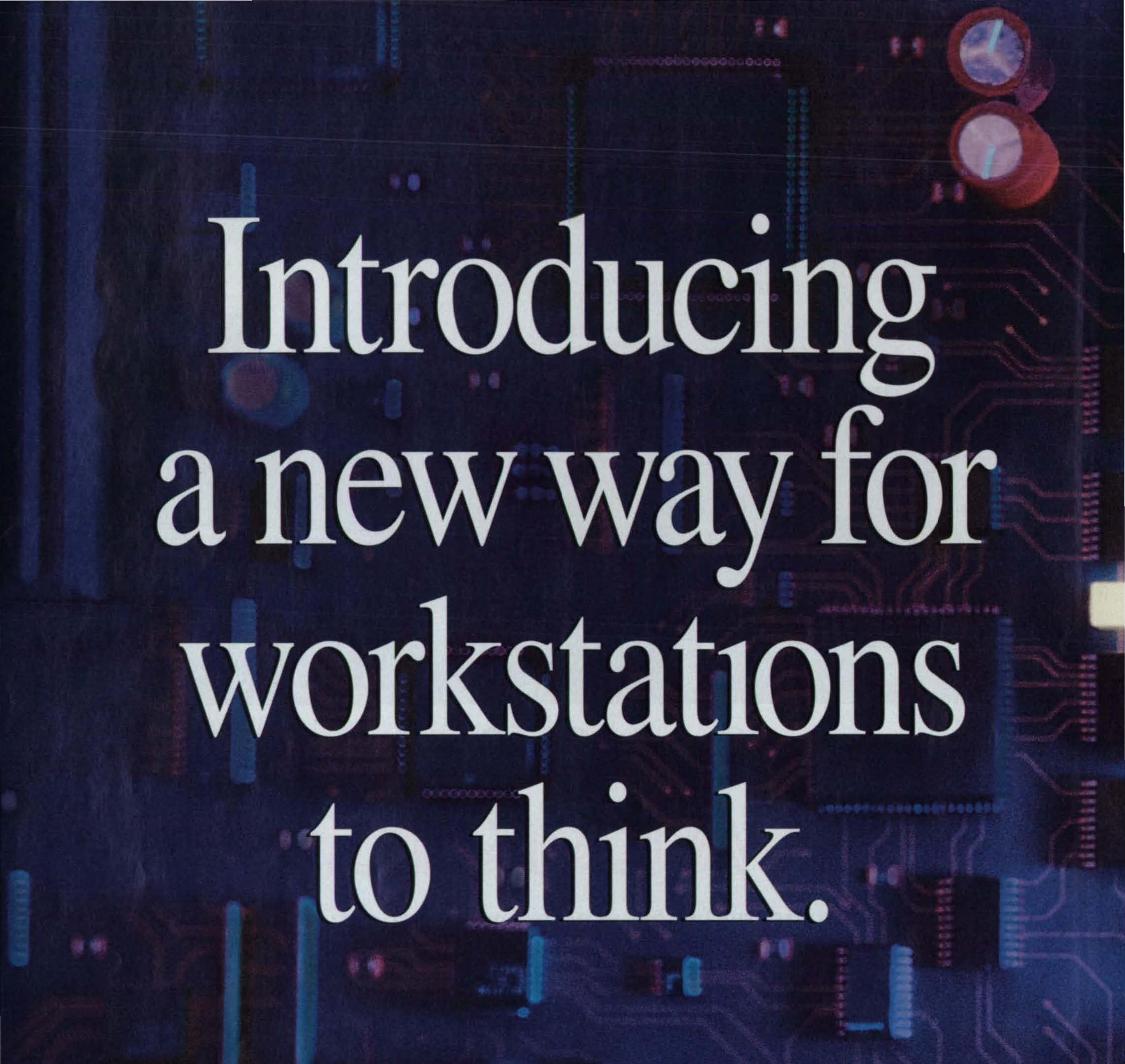

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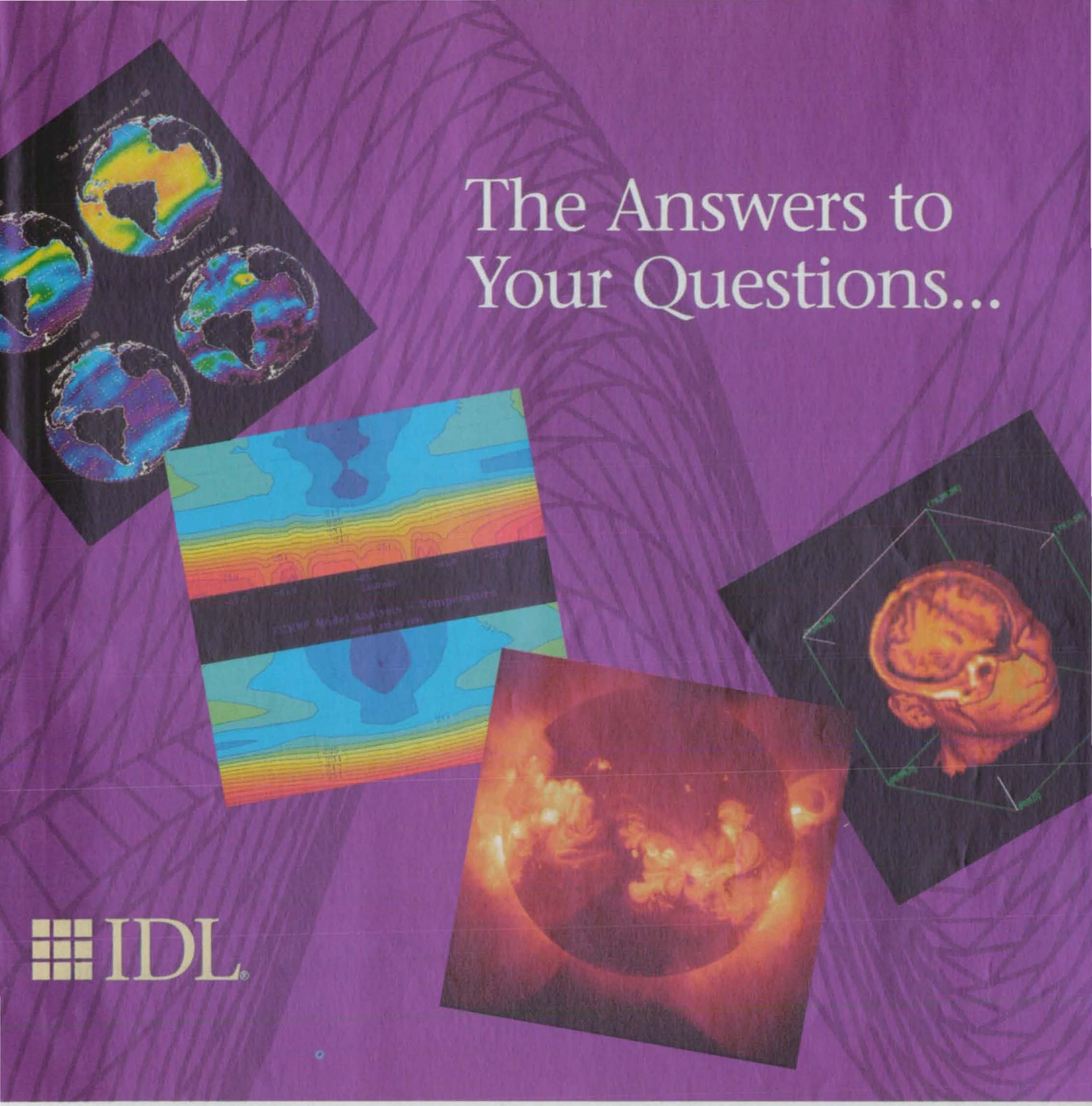

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New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Commercial Technology Office of the sponsoring NASA center (see page 14).

Integrated Oxygen-Recovery System

A developmental system revitalizes breathing air in an enclosed environment by converting carbon dioxide and water to oxygen and methane. Such a system is smaller, weighs less, and consumes less power than conventional systems using an electrolyzer and Sabatier reactor as distinct components.
(See page 52.)

Selective Oxidizer for Removal of Carbon Monoxide

Multiple catalytic stages at progressively lower temperatures operate without becoming poisoned. Here most of the carbon monoxide is oxidized in a stream of reformed fuel gas that is fed to a low-temperature fuel cell.
(See page 54.)

Silicon Carbide Transistor for Detecting Hydrocarbon Gases

A proposed transistor would be specifically designed for measuring concentrations of hydrocarbon gases. Such devices have numerous potential applications in automotive, industrial, aeronautic, and environmental monitoring applications.
(See page 55.)

Sensing Position With Approximately Constant Contact Force

A computer-controlled system uses a number of linear variable-differential transformers to measure axial positions of selected points on the surface of a lens, mirror, or other precise optical component with a high finish. The pneumatic pressure can extend the probes in 0.006-in. (0.15-mm) increments.
(See page 76.)

Helium-Recycling Plant

A proposed system would recover and store helium gas for reuse. Helium would be conserved with little contamination or back pressure on the source. Conservation of helium is becoming an important issue that could affect the development of new technologies and scientific discoveries in the 21st century.
(See page 81.)

NASA NEWS BRIEFS

Lewis Research Center has signed a Space Act Agreement with the Cleveland Clinic, establishing a three-year relationship for cooperative research. This marks the first agreement between NASA and an academic medical center.

Under the agreement, Lewis and the Cleveland Clinic Foundation's Department of Biomedical Engineering will engage in mutually beneficial research to develop products and technologies, and to solve technological problems related to orthopedic and cardiovascular devices, medical imaging, and microelectrical mechanical systems. The two are currently collaborating on the development of an artificial heart pump and computer-assisted minimally invasive surgery.

In another Space Act Agreement, Kirby Co. of Cleveland, OH, is working with Lewis to apply NASA technology to the company's line of vacuum cleaners. Using Lewis facilities and expertise, Kirby is researching advanced operational concepts such as particle flow behavior and vibration, which are critical to improving vacuum cleaner performance. Nozzle tests using a Lewis-developed technique called Stereo Imaging Velocity will enable Kirby researchers to accurately characterize fluid and air experiments. Kirby also is using Lewis' holography equipment to study vibration modes of jet engine fans.

For more information, contact the Lewis Office of Community and Media Relations at 216-433-2888.

The new $250-million Mission Control Center (right) is operating at NASA's Johnson Space Center in Houston. Designed, implemented, and integrated by Loral Space Information Systems of Houston, the center handles command and control of all NASA manned space vehicles. Loral architecture and infrastructure software provides all basic telemetry, trajectory, and command capabilities for planning and real-time control of space shuttle and international space station operations. The center uses approximately 90% commercial off-the-shelf (COTS) hardware and 30% COTS software, which are expected to lower NASA's operating costs by $20 million per year.

Spacecraft flight controllers use new consoles that provide integrated voice, video, and data via one of the world's largest Fiber Distributed Data Interface local area networks. The combined development and operational environments can store 3 terabytes of data, the equivalent of the information contained in a stack of paper 36.4 miles high. Combined shuttle and space station operations in the new center require only 197 workstations, compared with the 204 required previously. By 1999, the facility is expected to operate using only 700 equipment racks, compared to the 1400 used now for shuttle support alone.

For more information, contact Lisa Koppel at Loral Corp.; 703-416-5542.

Marshall Space Flight Center scientists have determined the three-dimensional atomic structure of an important enzyme from a species of parasite known to cause schistosomiasis, a disease that affects 200 to 300 million people worldwide for which there is no vaccine. The disease is second only to malaria in causing death. Victims become infected by any of four parasitic flatworms or flukes when wading or swimming in contaminated fresh water.

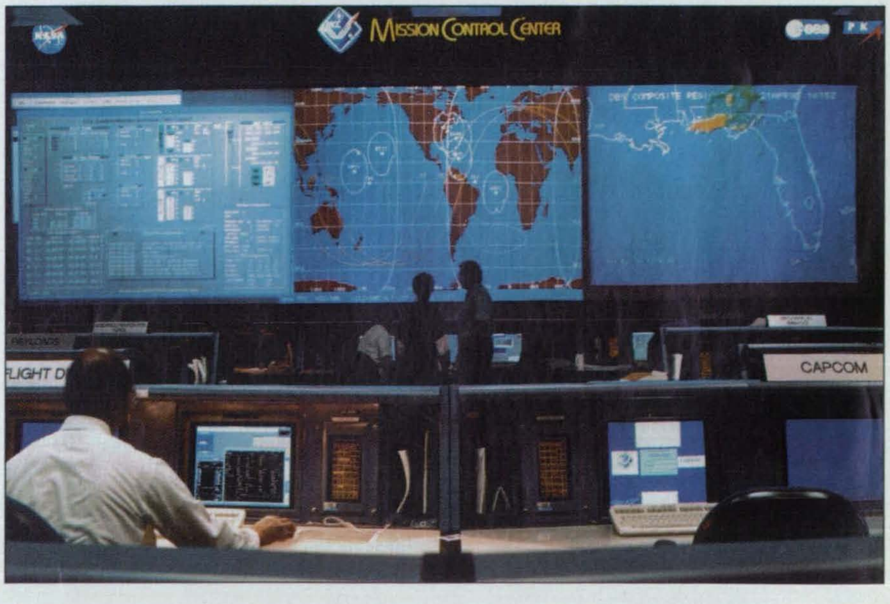
Dr. Daniel Carter, research director and chief of Marshall's Biophysics and Advanced Materials Branch of the Space Sciences Laboratory, said that this step "seems to offer the most potential for developing vaccines that protect people against the entire species of schistosomiasis parasites, not just one species." The determination of the enzyme structure offers the possibility of combining such techniques as the use of disease-fighting drugs with preventive vaccines to form a barrier against the transmission of the disease.

For more information, contact Dr. Daniel Carter at 205-544-5492.

Marshall scientists have determined that a NASA lightning detector may be used to identify the formation of tornadoes and severe storms from space. Using data from the Optical Transient Detector (OTD), Marshall researchers are building a global picture of the role lightning plays in the atmosphere, including lightning produced by large storms. The OTD, which was launched last year, has been observing lightning flashes as it passes over severe storms. The "flashrate" of lightning may provide, in conjunction with other detection systems, an indication of the formation of tornadoes.

For more information, contact the Marshall Public Affairs office at 205-544-0031.

NASA's Jet Propulsion Laboratory has developed a new infrared detector array that uses highly sensitive quantum-well IR photodetectors (QWIPs) to cover longer wavelengths than those possible with conventional mercury cadmium telluride and indium antimonide arrays. With the new technology, doctors may detect tumors using thermographic analysis and pilots may be able to make better landings



with improved night vision equipment. Other possible uses are pollution and weather pattern monitoring, drug and law enforcement applications, search and rescue, and industrial process control.

JPL has demonstrated two IR cameras using QWIP arrays for ground-based and space-based imaging. The lab currently is working with Amber, a Raytheon company in Goleta, GA, to develop QWIPs for new portable IR cameras.

For more information, contact Tom Hamilton of JPL at 818-354-7344.

SY Technology of Huntsville, AL, in partnership with MicroBioMed, the University of Kansas Medical Center, and the optics division of the Coherent Auburn group, was awarded a $600,000 Phase II Small Business Innovation Research (SBIR) grant from NASA to develop two diffractive optics-based systems for NASA and the medical community.

The first of the systems will be used by NASA to fabricate complex optical components which previously were not possible. The new components will be used in space telescopes and for making test optics to verify the performance of NASA-developed optical systems. The second system will demonstrate advanced surgical techniques which may eliminate the need for sutures in corneal transplants.

For more information, contact Greg Sharp of SY Technology at 205-722-9095.

NASA's Mid-Continent Technology Transfer Center (MCTTC) is attempting to locate capital sourcing for the Attitude Adjuster, an automatic adjustable weight system for scuba divers developed by Joe Nicklo of Think Tank Technologies in Houston, TX. The company already has received requests for prototypes from the U.S. Navy. The device consists of two tubes that fasten lengthwise to the diver's air tank. They are partially filled with lead shot that adjusts automatically with the diver's position, or attitude. The MCTTC has secured testing of the device at Marshall Space Flight Center's Weightlessness Environmental Training Facility.

For more information, contact Joe Nicklo of Think Tank Technologies at 713-933-9875.

The Air & Space Network, a premium television network devoted entirely to aviation and space programming, is scheduled to debut in May. The network will offer aviation news broadcasts and talk shows, including a daily aviation weather program; an aviation call-in program; coverage of military air shows; college aviation courses; a shopping program; educational, safety, aircraft, equipment, NTSB accident analysis, and legislative programming; and live coverage of NASA's manned and unmanned space flight, including space shuttle and other space exploration missions.

Entertainment services will include historic documentaries, biographies, feature films, air shows, special events, and aerospace news. Much of the programming will come from archives of federal and state governments, private foundations, aviation associations, and independent producers. The network will debut as a premium/mini-pay service offered on Direct Broadcast Satellite (DBS) and analog C-band satellite TV. Cable, wireless, and traditional broadcast channels will be added as capacity becomes available.

Computer-interactive services via telephone will be offered, including games, downloadable weather fax service, an air and space calendar of events, downloadable software, chat lines and bulletin boards, merchandise catalogs, and guides to services and products.

For more information, contact Matthew Simek of The Air & Space Network at 503-224-9821.

The National Technology Transfer Center opened its new headquarters building on the campus of Wheeling Jesuit College in May 1995.

NATIONAL TECHNOLOGY TRANSFER CENTER: *Serving the Nation's Industrial Competitiveness*

It might seem a long leap from the federal laboratory network to the local dry-cleaning establishment, but bringing the two together is just one of the more unusual successes of the National Technology Transfer Center (NTTC). Since its establishment in 1990, the center has acted on more than 10,000 technical requests and recorded more than 100,000 log-ons to its electronic information system.

Funded by NASA, and with additional support from the Ballistic Missile Defense Organization, the U.S. Navy, and other federal agencies, the NTTC has its headquarters on the campus of Wheeling Jesuit College in Wheeling, WV. From there it extends its reach throughout the country, drawing on the expertise of more than 700 laboratories and thousands of scientists, engineers, and managers who make up the Federal Laboratory Consortium. NTTC also teams with NASA's Regional Technology Transfer Centers (RTTCs)—six offices nationwide that assist local industry in technology evaluation and commercialization, as well as market assessment and other areas of business expertise.

NTTC's programs run the gamut of technology transfer initiatives. A key service is called the National Gateway, providing callers from business and industry free access to technology and expertise from the NASA labs and other federally funded research facilities. This is done through NTTC technology access agents, who, once apprised of a technical challenge or area of interest, search the proper databases, contact the labs, and often put the inquirer in touch with the individual experts who are the best resources.

But if the inquirer simply wants to browse through the ideas and technical information available from federal sources, there is Business Gold, a free service available via the Internet or direct modem connect. Operating 24 hours a day, NTTC's electronic bulletin board provides information that can be downloaded onto the user's computer free of all charges except for the phone lines. Included are descriptions of new technologies available for licensing and commercialization; NASA RTTC contacts; current SBIR, Technology Reinvestment Program, and similar solicitations; technology transfer conference calendars; information from government software centers; and more.

Forging Partnerships

NTTC acts either directly or through the regional network to facilitate technology transfer. When Hi-Shear Technology Corp. of Torrance, CA, was looking for a new design for the power unit for Lifeshear, a cutting tool for extracting auto accident victims from wreckage, NTTC provided the immediate link to NASA's Jet Propulsion Laboratory. An advanced technology for powering an initiator for multi-stage rockets and explosive bolts was co-developed for dual use under a JPL-managed Technology Reinvestment Project award to Hi-Shear. Federal Emergency Management Agency rescue workers later used Lifeshear at the Oklahoma City bombing site. (See "Mission Accomplished," *NASA Tech Briefs*, August 1995, Vol. 19, No. 8, page 20.)

Using the regional connection, NTTC referred Jay Carter Jr., president of CarterCopters Inc. of Wichita Falls, TX, and designer of a unique gyroplane, to the Mid-Continent Technology Transfer Center (MCTTC) in Texas. After MCTTC's evaluation, Carter was directed to NASA Ames Research Center officials, who helped him draw up a Small Business Innovation Research proposal that won a $70,000 award from NASA last fall. He hopes the CarterCopter will fly as early as the end of the year.

The Office of Law Enforcement Technology Commercialization (OLETC) is another recent example of NTTC's successful partnerships. The center hosts OLETC, a joint undertaking with NASA and the Justice Department's National Institute of Justice. Through it, NTTC funnels state-of-the-art law-enforcement product ideas to the manufacturing community, and arranges for rapid prototyping at test facilities. The center also provides timely funding information to law-enforcement and criminal justice organizations throughout the country to help them acquire advanced technology.

OLETC is pursuing several innovative projects, including a remote-controlled retractable roadway barrier strip that deflates tires, thus eliminating the hazards of high-speed auto chases; a "smart" gun that can be fired only by its owner; a pepper spray launcher-dispenser intended for use in efforts to free hostages; a disabling net and launcher system that deploys a lightweight net to trap escaping suspects; and concealed-weapons detection systems.

Last year the partners in OLETC presented Law Enforcement Technology Innovation Awards to Idaho National Engineering Laboratory (INEL) and 3M Law Enforcement Products. INEL designed a rear-seat air bag for patrol vehicles that restrains a violent apprehended suspect, preventing him from injuring himself or others or damaging the vehicle. 3M's fingerprint visualization system (FIVIS) is a small kit that detects prints left on nonporous surfaces at a crime scene by dispensing heated cyanoacrylate vapor over an area via a self-igniting wand.

Another critical function of OLETC is helping law-enforcement agencies find ways to pay for innovative equipment. The office has compiled a guide to federal law-enforcement technology funding sources that provides eligibility requirements, criteria for selecting proposals, and examples of funded projects.

Training for the Future

Education and training are significant aspects of NTTC's activities. Idea Contact™, a new program directed at federal lab and agency personnel, teaches scientists, engineers, and managers how to evaluate a technical innovation for its manufacturability, marketability, and usefulness to the commercial world. For small and medium-sized manufacturers, NTTC provides technology-driven industrial extension programs, concentrating on the use of federal technologies as a catalyst for economic revitalization. As part of the Technology Reinvestment Program, NTTC received a grant to work with the Pennsylvania Technical Assistance Program, Rensselaer Polytechnic Institute, and other manufacturing assistance groups to create a national curriculum for training industrial extension agents. Finally, in cooperation with Wheeling Jesuit College, NTTC has developed courses of study for bachelor and master of science degrees in technology management, innovation, commercialization, and technology transfer.

As for the dry-cleaning innovation, David Porter, president of Garment Care Inc. in Kansas City, came to NTTC with an idea that would eliminate the environmentally troublesome dry-cleaning chemical perchloroethylene. His rack-conveyer system would carry soiled clothes through a water-based ultrasound bath, eliminating the need for the traditional chemical. An NTTC agent searched the center's technology database and came up with a potential research partner: the Kansas City Department of Agriculture facility operated by AlliedSignal. Researchers there responded with 40 hours of free discussion and preliminary tests on swatches of material. The ultimate result was a two-year Department of Energy "mini-CRADA" award of $50,000 for full-fledged research and development.

The dry-cleaning industry "wants innovation that not only takes care of our environment, but also our wallets," Porter says. "That's why we're excited about the technology transfer possibilities now before us. NTTC has, in my opinion, great networking potential for small business."

At the Technology 2005 conference and exhibition in Chicago late last year, NASA Administrator Daniel Goldin (right) spoke to Jay Carter Jr. about the CarterCopter gyroplane, a model of which is seen behind them. NTTC's referral of Carter to NASA sources resulted in a Small Business Innovation Research grant. **(Photo: Bill Ingalls/NASA)**

To access the National Gateway, phone 1-800-678-6882; to reach Business Gold, use Internet: URL http://www.nttc.edu. For more information on the NTTC, phone Jim Reed, Deputy Director of Marketing, at (304) 243-4400. OLETC is searching for 1996 Technology Innovation Award candidates: call NTTC at 800-678-6882 for more information.

Special Focus: Computer-Aided Design and Engineering

Using Aerospace Technology To Design Orthopedic Implants

Methods for optimizing designs of turboprop blades have been applied to prosthetic knee joints.

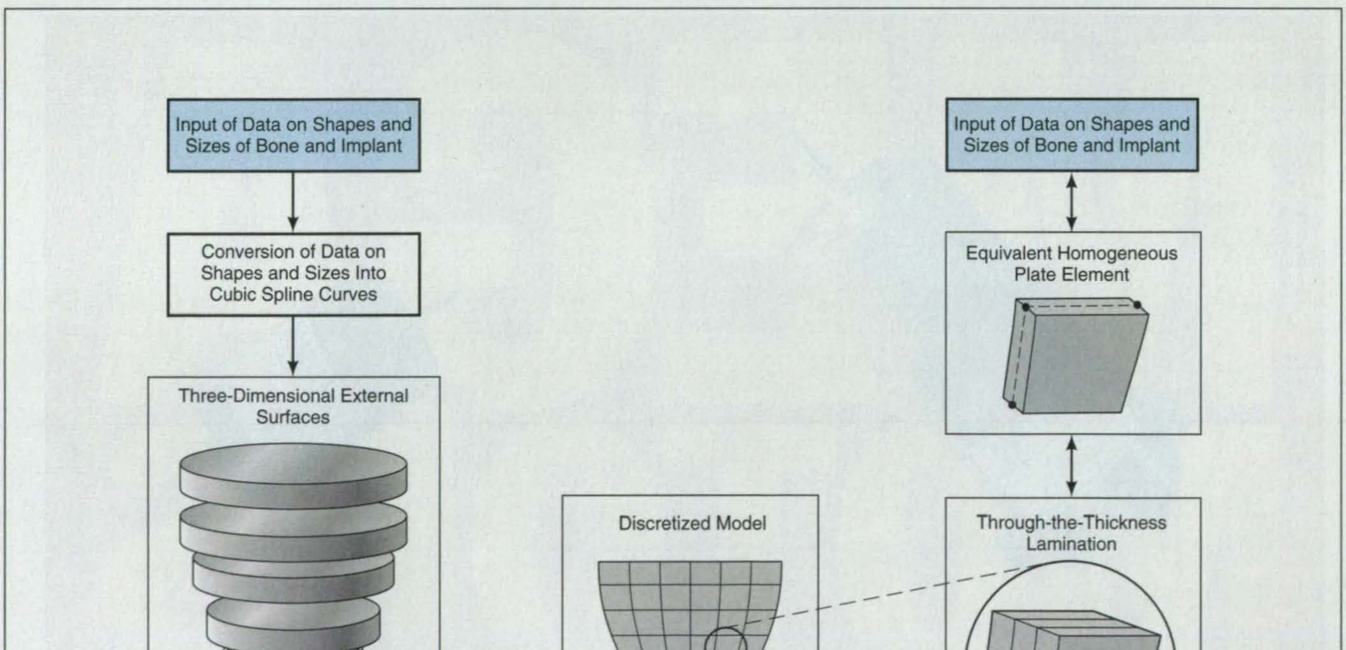
Lewis Research Center, Cleveland, Ohio

Technology originally developed to optimize the designs of composite-material aerospace structural components has found a new use in efforts to develop a method for optimizing the designs of orthopedic implants. Thus far, the development effort has focused on designing knee implants, but the long-term goal of this effort is to develop a method for optimizing the designs of orthopedic implants in general.

The prototype method provides for tailoring the shapes of the tibial components of a total-knee-replacement implant for optimal interaction within the environment of the tibia. The shapes of the components of the implant are optimized such that the stresses in the bone are distributed more favorably than they otherwise would be, thereby minimizing the degradation of bone, improving the mechanical integrity of the bone/implant system, and preventing failures of the components of the implant.

The computer code used in the prototype method is an adapted version of the Structural Tailoring of Advanced Turboprops (STAT) computer code. Despite the obvious differences between laminated composite turboprop blades on the one hand and bone/implant systems on the other hand, the essential features of STAT are applicable to both; these features include composite-mechanics, finite-element-analysis, and structural-optimization capabilities. An essential part of the optimization procedure is mathematical modeling of the quasi-static mechanical response of the laminated tissue structure of the upper end of the tibia. This modeling involves utilization of the finite-element-modeling capability of STAT and, in particular, laminated-plate models (see figure) as a compromise between overly simplistic two-dimensional models and fully complex three-dimensional models.

The analysis of stresses and strains takes place in three stages. In the first stage, stiffness matrices that represent the characteristics of the discrete bone



Laminated-Plate Models are used in the initial finite-element analysis of the bone/implant system.

layers are synthesized. Integration through the sagittal plane (thickness) provides the equivalent local through-the-thickness extensional and flexural stiffness matrices of the laminate, relating the generalized (average) laminate stresses to the generalized (average) laminate strains. In the second stage, the global static response is obtained via finite-element analysis with discretized nodal displacements in the frontal plane. The third and final stage involves the back-calculation of stresses within the bone and the implant components from the calculated global structural response. The generalized strains in the frontal plane are calculated, then the strain in each discretized layer is calculated. The stresses in the discretized material layers are then calculated from the layer strains.

The design parameters subject to optimization include those that specify the shape of a post and the thickness of a metal backing tray that are parts of the implant. The basic criterion for optimization of these parameters is assumed to be an acceptable state of stress in the bone/implant composite structure. For the tibial component, the most likely mode of failure is aseptic loosening, which involves the resorption of the bone adjacent to the implant. This is attributed in many cases to the stress-induced adaptation of the bone after the implantation surgery in response to the altered stress field induced exclusively by the presence of the implant. Thus, the optimal-design goal becomes the minimization of undesirable atrophy of the adjacent bone, or, in a positive sense, the creation of a favorable stress field in the bone.

Accordingly, the optimization-and-design procedure is an iterative one in which the shape of the post and the thickness of the metal backing tray are made to evolve in small increments, after each of which a finite-element analysis is performed to determine the new stress field. That information obtained at each such step of the design can then be used to direct the next design move in an effort to reach the optimum design by minimizing an objective function. The objective function chosen initially was the maximum specific distortion energy near the bone/implant interface.

This work was done by D. A. Saravanos, P. J. Mraz, and D. T. Davy of Case Western Reserve University for **Lewis Research Center**. *For further information,* ***write in 65*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center; (216) 433-2320. Refer to LEW-16093.

Multidisciplinary Design of Hot Composite Structures

A computer code incorporates modules for simulation and analysis by traditionally separate disciplines.

Lewis Research Center, Cleveland, Ohio

A unified computer code has been developed to implement a multidisciplinary approach to the design and analysis of composite-material structures that must withstand high temperatures. The code is modular: it includes an executive module that communicates with and coordinates other modules that perform calculations pertaining to traditionally separate disciplines like those of acoustics, structural vibrations, structural loads, and thermal effects (see Figure 1).

An essential feature of the multidisciplinary approach is finite-element numerical simulation of the relevant physical phenomena according to the applicable disciplines. The same finite-element mesh is used in the thermal, vibrational, and structural analyses; this minimizes data-preparation time and eliminates the errors incurred in transforming temperatures from one finite-element mesh to another.

The integrated multidisciplinary simulation procedure is founded, in part, on recognition of the essential complexity and nonlinearity of the coupled heat-transfer, geometrical, material-property, structural, acoustic and nonacoustic vibrational, and environmental effects. For example, the thermal, mechanical, and acoustic properties of a composite material are nonlinear functions of temperature and other environmental parameters. Accordingly, the unified program includes a module that contains the Integrated Composite Analyzer (ICAN) computer program, which implements micromechanics- and laminate-oriented mathematical models of composite materials to compute both the macroscale and the local microscale hygro/thermo/mechanical responses of composite materials, including effects of deterioration of properties with time.

Figure 2 illustrates the multidisciplinary design-tailoring and analysis proce-

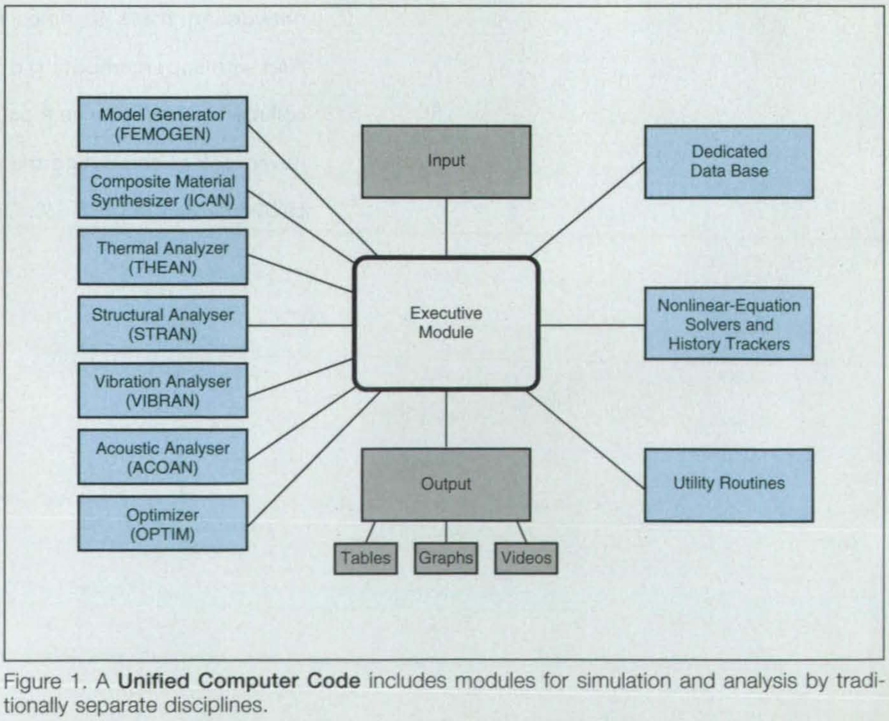


Figure 1. A **Unified Computer Code** includes modules for simulation and analysis by traditionally separate disciplines.

dures. The first step in the design-tailoring procedure is the specification of the tailoring input, which consists of an objective function, design variables, constraints, and convergence tolerances. The next step is to establish the current design via an initial multidisciplinary analysis based on values of the current design variables. The mathematical representation of the discipline-specific loads (e.g., thermal and mechanical loads) activates the corresponding multidisciplinary analysis modules.

The rest of the tailoring procedure is iterative. The gradients of the objective function and constraints are computed with respect to the design variables. A search vector is defined. A new set of design variables is chosen along the direction of the search vector. Again using the multidisciplinary analysis module, a proposed design based on the new design variables is then formulated and the physical behavior of the structure with the proposed design is simulated numerically. Then the objective function, the design variables, and the constraints are checked, on the basis of specified tolerances, to determine whether the proposed design is optimum. The procedure is repeated until an optimum design that satisfies all the constraints is achieved.

This work was done by Christos C. Chamis of **Lewis Research Center** *and Surendra N. Singhal of NYMA. For further information,* ***write in 64*** *on the TSP Request Card. LEW-15977*

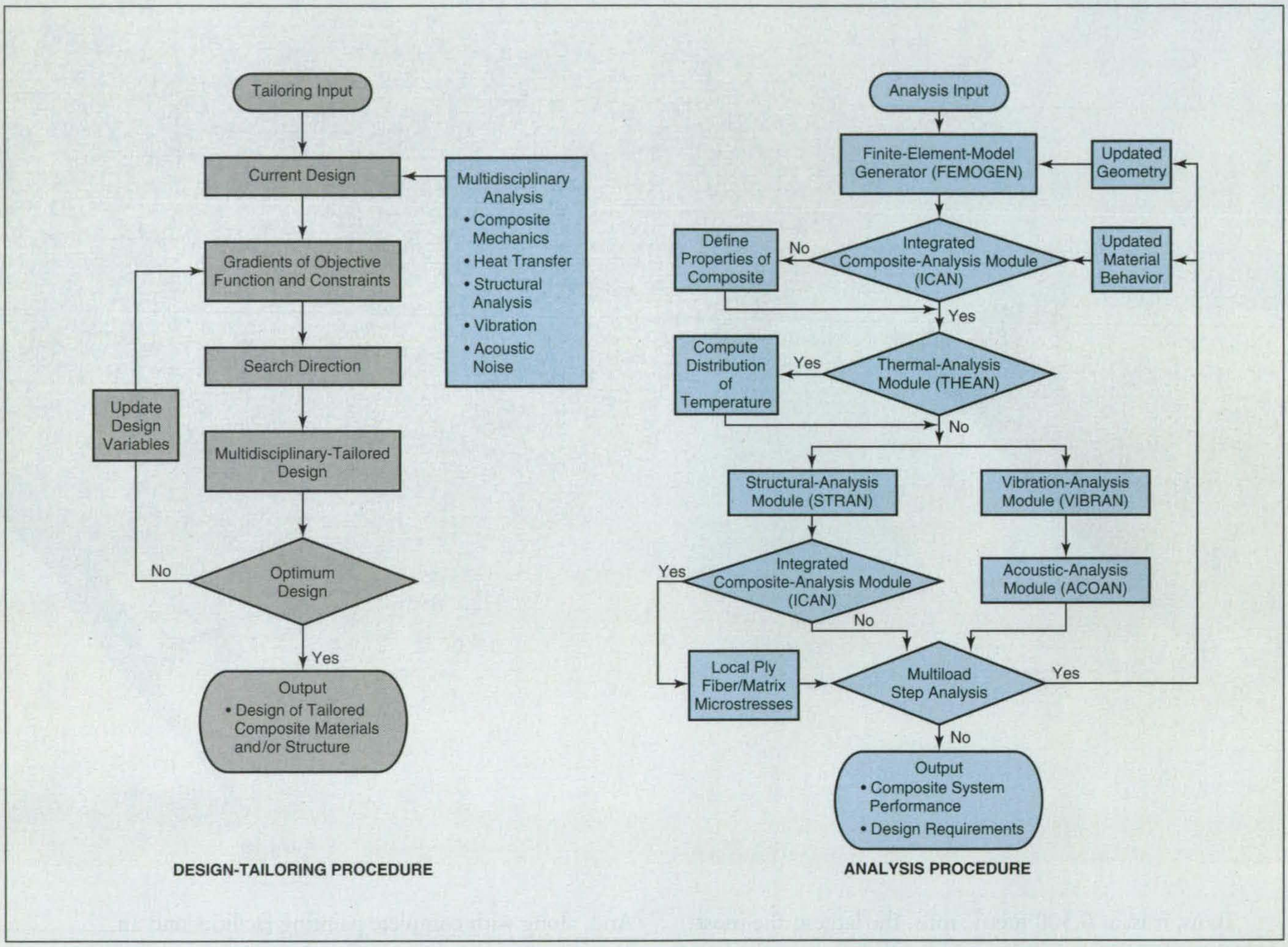


Figure 2. **Multidisciplinary Design and Analysis Procedures** that are implemented in the computer code reflect the nonlinearity and complexity of the relevant physical phenomena and of the design process.

Computer-Aided Process Model for Carbon/Phenolic Materials

The model can be used to optimize curing processes and predict the properties of the materials.

Marshall Space Flight Center, Alabama

A computer program implements a thermochemical model of the processing of carbon-fiber/phenolic-matrix composite materials into molded parts of various sizes and shapes. The program and model are subjects of a continuing development effort. Although this effort is directed toward improving the fabrication of rocket-engine-nozzle parts made of carbon/phenolic materials, the model can also be used to optimize the fabrication of other structural compo-

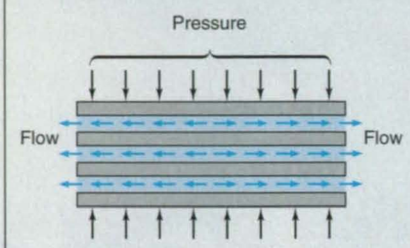
nents, and its material-property parameters can be changed to apply to other materials. The model helps to reduce costs by reducing the amount of laboratory trial and error needed to optimize curing processes and to predict the properties of the cured parts.

The program and model are based on the SINDA heat-transfer program and model. The program incorporates sophisticated computer-graphical capabilities; it can provide a three-dimensional view of a part being analyzed, the position of the part in the nozzle or other overall structure, and cross-sectional views of changes in temperature, degree of cure, moisture, and viscosity during the curing process. The model includes submodels of the transfer of heat, thermochemical reactions, generation and diffusion of moisture, viscosity, and the degree of cure. These submodels have been verified in laboratory tests.

A submodel of the flow of resin under pressure (see figure) is planned. This submodel will be based on data from flow tests in a laboratory. The model has been verified by correlation with data on a commercial carbon-cloth/phenolic composite. With suitable adjustments of kinetics parameters, the predictions of the model also seem to be well correlated with data on some other composite materials.

Several enhancements of the program and model are planned. The first would be modification of the program to make it easier to use; anyone who has minimal knowledge of SINDA but at least some knowledge of computers would be able to use the model. The second enhancement would be completion and verification of the resin-flow submodel. The third enhancement would be the addition of a submodel and code for the calculation of residual stresses and of compaction during cure.

This work was done by Mischell A. Letson and Robert C. Bunker of Thiokol Corp. for **Marshall Space Flight Center**. *For further information,* ***write in 26*** *on the TSP Request Card. MFS-28969*



Some of the Matrix Resin Flows out from between plies when a fiber/matrix composite laminate is squeezed during the curing process.

Program for Evaluation of Reliability of Ceramic Parts

This program predicts the probability of failure as a function of time in service.

Lewis Research Center, Cleveland, Ohio

Successful application of advanced ceramics depends on proper characterization of material properties and the use of probabilistic methodology for designing parts made of brittle materials. CARES/LIFE is a computer program for predicting the probability of failure of a monolithic ceramic component as a function of its time in service.

Probabilistic component design involves predicting the probability of failure of a thermomechanically loaded component from specimen rupture data. Typically, experiments to acquire these data are performed by use of many simple-geometry flexural or tensile test specimens. A static, dynamic, or cyclic load is applied to each specimen until fracture. Statistical strength fatigue parameters are then determined from these data.

Using these parameters and the results obtained from a finite-element analysis, the time-dependent reliability for a complex component geometry and loading is then predicted. Appropriate design changes are made until an acceptable probability of failure has been reached. This design methodology combines the statistical nature of strength-controlling flaws with the mechanics of crack growth to allow for multiaxial stress states, concurrent (simultaneously occurring) flaw populations, and subcritical crack growth (SCG).

CARES/LIFE predicts the probability of failure of a monolithic ceramic component as a function of service time. It assesses the risk that the component will fracture prematurely as a result of SCG. The effect of proof testing of components prior to service is also considered. CARES/LIFE is coupled to such commercially available finite-element programs such as ANSYS, ABAQUS, MARC, MSC/NASTRAN, and COSMOS/M. It also retains all of the capabilities of the previous CARES code, which include estimation of fast-fracture component reliability and Weibull parameters from inert strength (without SCG contributing to failure) specimen data. CARES/LIFE can estimate parameters that characterize SCG from specimen data as well.

Finite-element heat transfer and linear-elastic stress analyses are used to determine the distributions of temperature and stress in a component. The reliability at each element is calculated under the assumption that randomly distributed volume flaws and/or surface flaws control the failure response. The overall component reliability is the product of all the element-survival probabilities. CARES/LIFE generates a data file containing element risk-of-rupture intensities (a local measure of reliability) for graphical rendering of the critical regions of a structure.

CARES/LIFE describes the probabilistic nature of the strength of a material, using the Weibull cumulative distribution function. The Weibull equation is based on the weakest-link theory (WLT), in which it is assumed that the structure is analogous to a chain with many links. Each link may have a different limiting strength. When a load is applied to the structure such that the weakest link fails, then the structure fails.

The effect of multiaxial stresses on reliability is predicted by using the principle of independent action (PIA), the Weibull normal-stress-averaging method (NSA), or the Batdorf theory. For the PIA model, the reliability of a compo-

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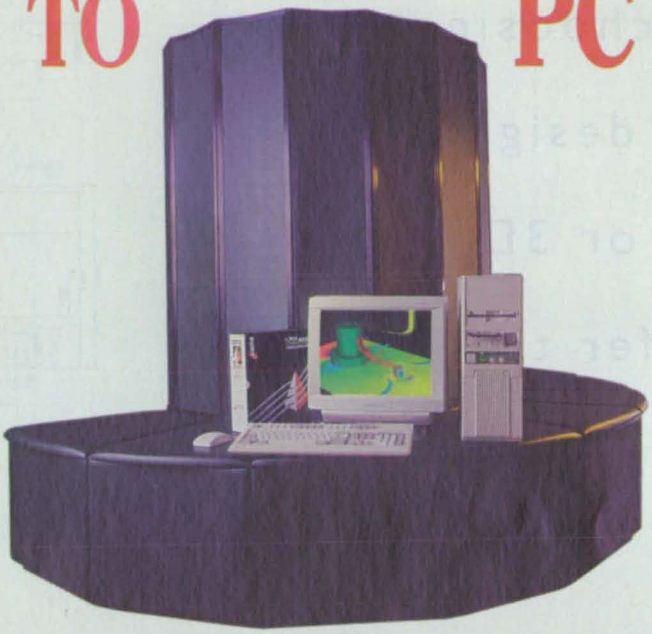
FROM SUPERCOMPUTER TO PC



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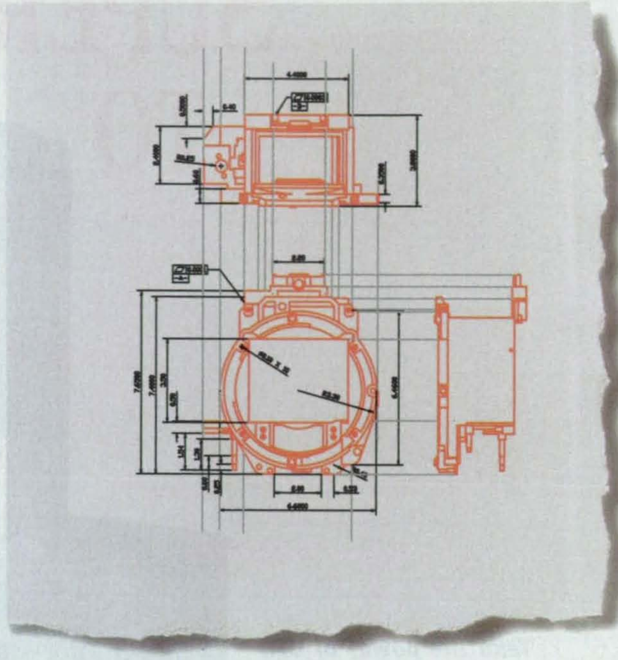

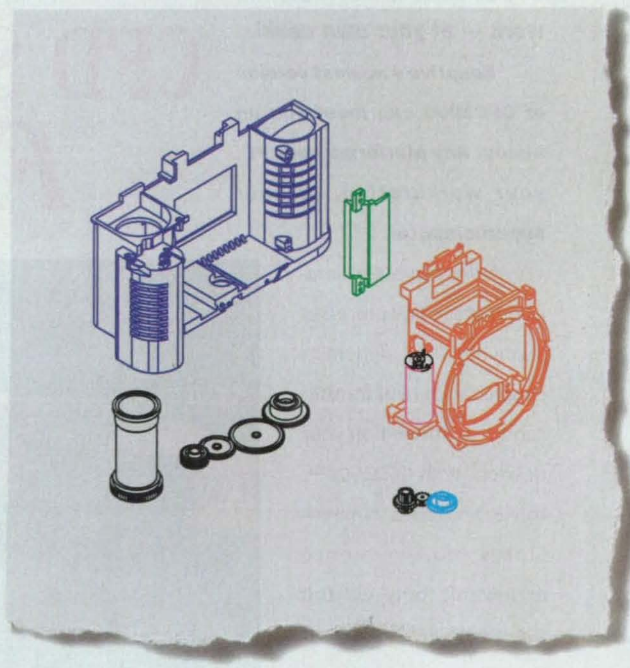

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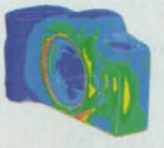

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(continued from page 28)

nent under multiaxial stresses is the product of the reliability of the individual principal stresses acting independently. The NSA method involves the integration and averaging of tensile normal stress components evaluated about all possible orientations and locations. This approach is a special case of the more general Batdorf theory and involves the assumption that the material is insensitive to shear.

The Batdorf theory combines the WLT and linear elastic fracture mechanics (LEFM). A flaw geometry selected by the user and a mixed-mode fracture criterion are required to model volume- or surface-strength-limiting defects. "Mixed-mode fracture" refers to the ability of a crack to grow under the combined actions of a normal load (opening mode) and shear load (sliding and tearing modes) on the crack face.

In CARES/LIFE, the relations that describe subcritical crack growth are directly incorporated into the PIA, NSA, and Batdorf theories. Subcritical crack growth is modeled with the power law, the Paris law, and the Walker law for static and constant-amplitude cyclic loading. These laws use experimentally determined parameters that are material- and environment-sensitive.

Predicted lifetime reliability of structural ceramic components depends on Weibull and fatigue parameters estimated from widely used tests that involve flexural or tensile specimens. CARES/LIFE estimates fatigue parameters from naturally flawed specimens ruptured under static, cyclic, or dynamic (constant stress rate) loading. Fatigue and Weibull parameters are calculated from rupture data on three-point and four-point flexure bars as well as tensile specimens. For other specimen geometries, finite-element models of the specimens are also required when estimating these parameters.

CARES/LIFE is written in ANSI FORTRAN 77 to be machine-independent. Therefore, the program will run on any computer in which sufficient addressable memory (at least 8MB) and a FORTRAN 77 compiler are available. The CARES/LIFE software package has been successfully implemented on DEC VAX computers running VMS, Sun4-series computers running SunOS 4.1.3, Silicon Graphics computers running IRIX 5.2, and DECstation-series computers running DEC RISC ULTRIX. Sample output files from the ANSYS (Swanson Analysis Systems, Inc.), MSC/NASTRAN (MacNeal-Schwendler Corp.), and ABAQUS (Hibbitt, Karlsson, and Sorenson, Inc.) commercially available finite-element-analysis software packages are included with the distribution. For an IBM-compatible personal computer with a minimum 640K memory, a limited program is available (CARES/PC, COSMIC number LEW-15248). The standard distribution medium for CARES/LIFE is a 0.25-in. (6.35-mm) streaming-magnetic-tape cartridge (Sun QIC-24) in UNIX tar format. Alternate distribution media and formats are available upon request. CARES/LIFE was released in 1994.

This program was written by N. Nemeth, L. A. Janosik, and J. P. Gyekenyesi of **Lewis Research Center** *and Lynn M. Powers of Cleveland State University. For further information,* ***write in 96*** *on the TSP Request Card. LEW-16018*

TSS — Thermal Synthesizer System

This software can greatly expedite the thermal-engineering process.

Lyndon B. Johnson Space Center, Houston, Texas

The Thermal Synthesizer System (TSS) is an integrated set of thermal-analysis application programs that is designed to solve problems encountered by thermal engineers. TSS combines the functionality of Systems Improved Numerical Differencing Analyzer/Fluid Integrator (SINDA/FLUINT) and radiation analysis with a friendly and easily understood user-interface environment coupled with powerful interactive color graphics and geometric modeling capability. The effort expended on developing this means of interaction has resulted in a system that is easy and straightforward to use. This system will enable thermal engineers to spend more of their time solving engineering problems instead of laboriously constructing and verifying math models.

TSS functionality is logically grouped into a number of application programs. The Executive application program serves as the starting point for all other TSS application programs. This application program also encapsulates UNIX functionality into a user-friendly interface. The Geometry application program facilitates construction, verification, and display of thermal-radiation mathematical models as well as solid and shell models for subsequent processing by the Radiation Conductance (RADK), Heatrate, Conductance-Capacitance, and Image application programs.

The RADK application program allows calculation of thermal-radiation form factors, interchange factors, and radiation conductances through use of Monte Carlo ray-tracing techniques. RADK output is compatible with SINDA/FLUINT, also included in TSS. The Orbit application program provides a means of creating and visualizing orbits for subsequent use by the Animation and Heatrate application programs. The Orbit application program operates in six different modes: basic, Keplerian, Sun-referenced, date-dependent, heliocentric, and planetary surface. The Animation application program facilitates the articulation of model geometries (in either an orbiting or a geometry-only mode) for subsequent processing by the RADK and Heatrate application programs. Each object within a geometric model can be articulated in one of four animation modes: velocity plus rotation rate, positional interpolation, inertial tracking, or point tracking.

Users may specify artificial radiant-heat sources within the Heatsource application program. Four different types of artificial sources may be specified: infinite parallel, point, nodal diffuse, and infinite diffuse. Both solar and infrared spectrum sources are supported. The Heatrate application program enables characterization of orbit environments, planetary surface environments, and artificial heating. Orbit-environment calculations provide for computation of solar, albedo, and planetary heating components. The Conductance-Capacitance application program facilitates the creation of a SINDA/FLUINT-compatible thermal-network model as derived from the geometry specified by the user. Nodal capacitances and intraobject conductances are automatically calculated. Interobject conduction paths are easily generated.

The SINDA/FLUINT application program, included with TSS, is the same SINDA/FLUINT program that is available on many platforms (Version 2.6). Models created within TSS can be processed within SINDA/FLUINT or exported to external systems. Conversely, any existing SINDA/FLUINT model can be ported into the TSS system and processed. The FLUINT Modeler application program enables the construction, display, and verification of single- or two-phase flow networks and creates SINDA/FLUINT-compatible input decks. This application program also supports postprocessing of the model results onto the geometric representation of the flow network.

The Thermal Radiation Analysis System (TRASYS) to Geometry Translator converts models in the TRASYS input-deck format into the TSS Geometry Input Language. The Geometry to TRASYS Translator converts models in the TSS Geometry Input Language format into the TRASYS input-deck format.

Results from TSS analyses, ASCII data, and flight data can be plotted in the XY Plot application program, which is included with TSS. Users can work with up to eight different sets of data simultaneously. Customization of plots, comparison-plotting of sets of data, and curve fitting are also available. Geometries defined by users can be processed in the Image application program to provide photorealistic images to support engineering analysis, presentations, and documentation.

TSS has been under development for many years. It was first released in 1993. TSS is available from COSMIC (v2.0) by license for a period of ten years to approved licensees. The licensed program product includes the executable code and one copy of the supporting documentation. Additional copies of the documentation may be purchased separately at any time.

TSS is written in FORTRAN and C language for Apollo DN10000VS and HP 700-series computers running Domain and UNIX operating systems, respectively. The program requires 32MB of random-access memory and at least 500MB of disk space. For the Apollo workstations, TSS requires 40-bit-plane graphics, Domain 3-D graphics Metafile and Domain Dialogue. For the HP-series workstations, TSS requires the CRX 24Z graphics upgrade, HPUX 9.05, and the PHIGS run-time library. A FORTRAN-77 compiler is required for the SINDA/FLUINT application.

The standard distribution medium is magnetic tape. For the Apollo computers, the program is distributed on 60MB, 0.25-in. (6.35-mm) streaming-magnetic-tape cartridge in rbak format, which is readable on a Domain Dialogue 60MB tape drive. For the HP-series workstations, the program is distributed on 4-mm tape in tar format, readable under standard UNIX environments.

This program was developed by Edward Chimenti, Steven Rickman, Robert Vogt, and Carlos R. Ortiz Longo of **Johnson Space Center***; Noel Bauman, Joseph Lepore, Phil Mackey, James Pavlovsky II, Mark Welch, and Peter Fogerson of Lockheed Engineering and Sciences Co.; and Mark Dawber, Cynthia Jone Fong, Peter Hecke, Susan Morrison, Ernie Castillo, Zu Chou, Lawrence Fried, Jerry Howard, Mike Lombardi, Jack Middleton, Tim Panczak, and Brett Preston of Lockheed Missiles and Space Co. For further information,* ***write in 86*** *on the TSP Request Card.*
MSC-22420

Program Calculates Current Densities of Electronic Designs

The current in each component is averaged over the area occupied by the component.

NASA's Jet Propulsion Laboratory, Pasadena, California

The PDENSITY computer program calculates current densities for use in calculating power densities of electronic designs. PDENSITY reads a parts-list file for a given design, a file that contains the current required for each part, and a file that contains the size of each part. Then for each part in the design, the program calculates the current density in units of milliamperes per square inch (1 mA/in.^{2} = 0.155 mA/cm^2).

The user invokes PDENSITY with the input parts list, the current-requirements file, the size file, and the name of the output file. Any parts not in the current-requirements file are reported, and the current-requirements file can be modified for particular needs.

PDENSITY is written by use of the AWK utility for Sun4-series computers running SunOS 4.x and IBM PC-series and compatible computers running MS-DOS. The program was written to be used with the OrCad Schematic Capture Program, but also can be used with a list of parts in ASCII format. The UNIX "nawk" utility is used to run the Sun version of PDENSITY. The Sun version of the program (NPO-19588) has been successfully implemented on a Sun4-series computer running SunOS 4.1.3. The PC version of the program (NPO-19171) has been successfully implemented on a DECpc 486-series computer running MS-DOS v6.2. A sample executable file is provided for the PC version of PDENSITY. The standard distribution medium for the Sun version of PDENSITY is a 3.5-in. (8.89-cm), 1.44MB diskette in UNIX tar format. The standard distribution medium for the PC version of PDENSITY is one 3.5-in. (8.89-cm), 1.44MB, MS-DOS-format diskette. An electronic copy of the documentation in Microsoft Word v2.0 for MS-DOS format is included on all distribution media. PDENSITY was released in 1995 and is a copyrighted work with all copyright vested in NASA.

This program was written by Brian Cox of Caltech for **NASA's Jet Propulsion Laboratory**.

For further information on NPO-19588, ***write in 63*** *on the TSP Request Card.*

For further information on NPO-19171, ***write in 66*** *on the TSP Request Card. NPO-19588/NPO-19171*

Computing Operating Characteristics of Bearing/Shaft Systems

SHABERTH incorporates up-to-date mathematical models of thermal and mechanical phenomena.

Marshall Space Flight Center, Alabama

The SHABERTH computer program predicts operating characteristics of bearings in a multibearing load-support system. Lubricated and nonlubricated bearings can be modeled. SHABERTH calculates the loads, torques, temperatures, and fatigue lives of ball and/or roller bearings on a single shaft. The program also provides for analysis of the reaction of the system to the termination of the supply of lubricant to the bearings and other lubricated mechanical elements. SHABERTH has proven to be valuable in the design and analysis of shaft/bearing systems.

The SHABERTH program is structured with four nested calculation schemes. A thermal scheme performs both steady-state and transient calculations that predict temperatures in the system in a given operating state. A bearing-dimensional-equilibrium scheme uses (1) bearing temperatures predicted by the temperature-mapping subprograms in the thermal scheme and (2) distributions of loads on rolling-element raceways as predicted by a bearing subprogram, to calculate (3) diametral clearances of bearings in a given operating state. A shaft/bearing-system load-equilibrium scheme calculates positions of inner rings of bearings relative to the respective outer rings, such that the external loads applied to the shaft are brought into equilibrium by the rolling-element loads that develop at each inner ring in a given operating state. A bearing-rolling-element-and-cage load-equilibrium scheme calculates the equilibrium positions and the speeds of rotation of rolling elements and cages on the basis of relative positions of inner and outer rings, inertial effects, and friction.

The current version of SHABERTH contains ball-bearing subprograms that are enhanced, in comparison with similar programs, by the incorporation of several mathematical models. These include

- An elastohydrodynamic (EHD) film-thickness model that accounts for heating and lubricant-film starvation in the contact area;
- A new model for traction combined with an asperity-load-sharing model;
- A model for the hydrodynamic rolling and shear forces in the inlet zones of lubricated contacts, which model accounts for the degree of lubricant-film starvation;
- A model of normal and friction forces between a ball and a cage pocket, which model accounts for the transition between the hydrodynamic and elastohydrodynamic regimes of lubrication; and
- A model of the effect, on fatigue life, of the ratio between the thickness of the EHD plateau film and the composite surface roughness.

SHABERTH is intended to be as general as possible. The models in SHABERTH provide for the complete mathematical simulation of real physical systems. A simulated system is limited to a maximum of five bearings supporting a shaft, a maximum of 30 rolling elements per bearing, and a maximum of 100 temperature nodes. The structure of the SHABERTH program is modular and has been designed to enable refinement and replacement of various component models as needs and opportunities develop.

SHABERTH is available in Cray and

IBM PC versions. A preprocessor subprogram is included in the IBM PC version to provide a user-friendly means of developing SHABERTH models and executing the resulting code. The preprocessor enables the user to create and modify data files with minimal effort and a reduced chance for errors. Data are utilized as they are entered; the preprocessor then decides what additional data are needed to complete the model in question. Only these needed data are requested. The preprocessor can accommodate input of data for any shaft/bearing-system mathematical model compatible with SHABERTH. The system to be simulated can include ball bearings, cylindrical roller bearings, and/or tapered roller bearings.

The two versions of SHABERTH are available from COSMIC. The Cray version [LEW-14860, "Computing Thermal Performances of Shafts and Bearings," *NASA Tech Briefs*, Vol. 16, No. 3 (March, 1992), page 67] requires a random-access memory (RAM) of 176K of 64-bit words. The IBM PC version (MFS-28818, this article) is written for IBM PC-series and compatible computers running MS-DOS and includes a sample MS-DOS executable code. For execution, the PC version requires at least 1MB of RAM and computer that contains an 80386 or 486 processor with an 80 × 87 math coprocessor. The standard distribution medium for the IBM PC version is a set of two 5.25-in. (13.335-cm), 360K, MS-DOS-format diskettes. The contents of the diskettes are compressed by use of the PKWARE archiving software tools. The utility software to unarchive the files, PKUNZIP.EXE, is included. The standard distribution medium for the Cray version is also a 5.25-in. (13.335-cm), 360K, MS-DOS-format diskette, but alternate distribution media and formats are available upon request.

The original version of SHABERTH was developed in FORTRAN IV at Lewis Research Center for use on a UNIVAC 1100-series computer. The Cray version was released in 1988, and was updated in 1990 to incorporate fluid-rheological data for Rocket Propellant 1 (RP-1), thereby enabling the analysis of bearings lubricated with RP-1. The PC version is a port of the 1990 Cray version and was developed in 1992 by SRS Technologies under contract to NASA's Marshall Space Flight Center.

This program was written by James D. Moore of **Marshall Space Flight Center**. *For further information,* ***write in 13*** *on the TSP Request Card.*
MFS-28818

Electronic Components and Circuits

Antennas for Receiving Signals Broadcast via Satellites

Small, inexpensive units have been designed for outdoor and indoor uses.

NASA's Jet Propulsion Laboratory, Pasadena, California

Four different antennas have been designed for use in receiving radio AM and FM signals broadcast via Earth-orbiting satellites at a carrier frequency of 2.05 GHz in right-hand circular polarization. These antennas are small, lightweight, inexpensive units with low-to-medium-gain, quasi-omnidirectional radiation patterns.

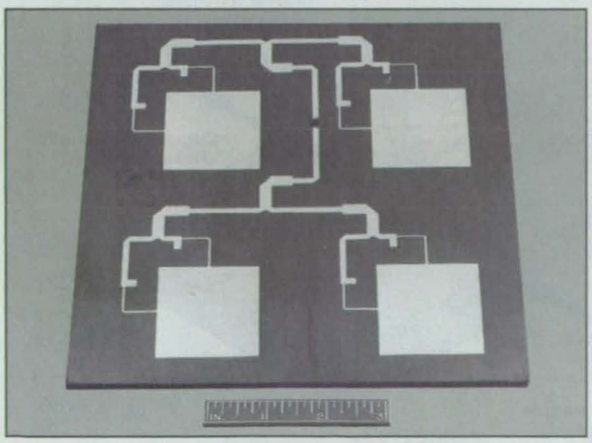
The first antenna, shown in the top left part of the figure, includes two crossed drooping dipoles protruding from a shaft, plus an impedance-matching tuning ring on the shaft. Each arm in one of the dipoles is 1.2 in. (30.5 mm) long; each arm in the other dipole is 1.8 in. (45.7 mm) long. The height of the dipoles above the automobile roof or other ground plane can be adjusted to optimize performance. In one test, for example, the dipoles were set at a height of 3.2 in. (81.3 mm), yielding a radiation pattern that peaked at 60° below the zenith, with a peak gain of 4.8 dBic (where "dBic" denotes decibels with respect to isotropic, circularly polarized radiation).

The second antenna, shown in the top right part of the figure, includes a circular conductive TM_{21}-mode-radiating patch of 5.2-in. (132-mm) diameter on a honeycomb dielectric plate of 6-in. (152-mm) diameter and 0.5-in. (12.7-mm) thickness. The patch is connected, at four locations near its periphery, to four ports of a printed-circuit-board stripline feed network that provides the amplitude and phase relationships for reception of right-hand circular polarization. This antenna is also intended for outdoor use. In a test, this antenna provided a peak gain of 6.5 dBic at an angle of 36° below the zenith.

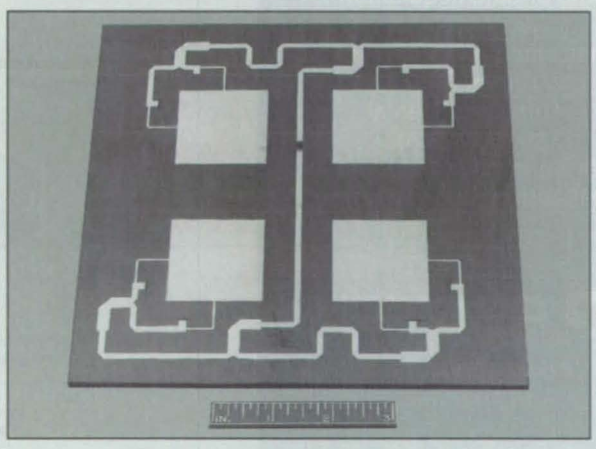
The other two antennas are medium-gain units designed for indoor use. These antennas contain 2 × 2 arrays of printed-circuit square conductive patches and microstrip feed lines that provide the required amplitude and phase relationships. Both of these antennas are fabricated on dielectric substrates of

CROSSED DROOPING DIPOLES

TM_{21}-MODE CIRCULAR MICROSTRIP PATCH ANTENNA



SQUARE PATCHES WITH CONVENTIONAL FEED



SQUARE PATCHES WITH SEQUENTIAL FEED

These **Small, Inexpensive Antennas** are suitable for reception of satellite broadcasts in right-hand circular polarization at a frequency of 2.05 GHz.

0.126-in. (3.2-mm) thickness. These antennas differ from each other in their microstrip feed configurations and in their lateral dimensions, which are 8.5 × 8.5 in. (216 × 216 mm) for one and 8 × 8 in. (203 × 203 mm) for the other. The measured broadside gains of the units were 12.0 and 13.7 dBic, respectively.

This work was done by Te-Kao Wu and John Huang of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 98*** *on the TSP Request Card. NPO-19362*

Split-Waveguide Mounts for Submillimeter-Wave Multipliers and Harmonic Mixers

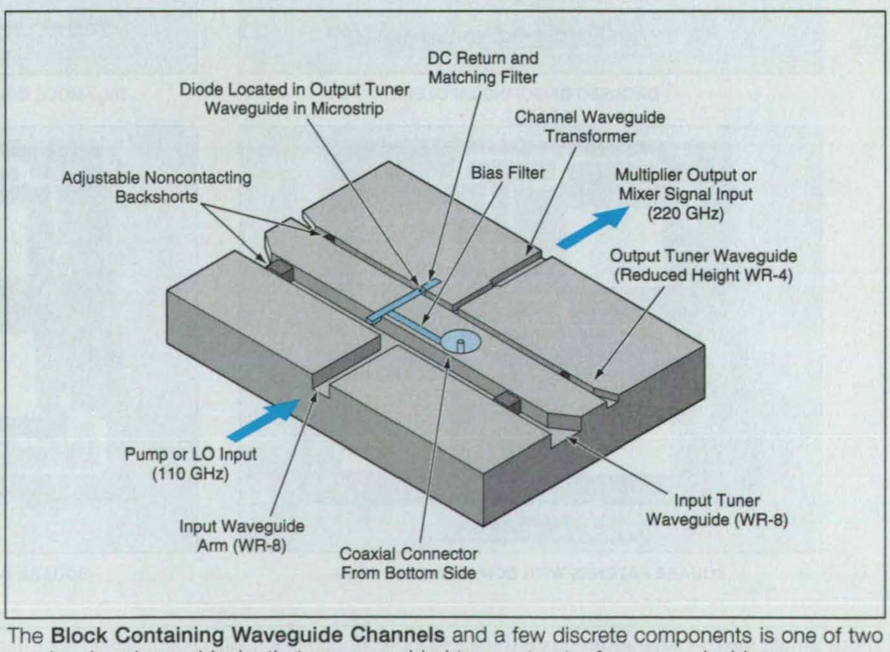
Advantages include ease of fabrication, reliability, and tunability.

NASA's Jet Propulsion Laboratory, Pasadena, California

A novel variation of a split-waveguide mount for millimeter- and submillimeter-wavelength frequency multipliers and harmonic mixers has been developed. The mount was designed to offer a wide range of available matching impedances, while maintaining a relatively simple fabrication sequence. The wide tuning range is achieved with separate series and parallel elements, which consist of two pairs of noncontacting sliding backshorts, at the fundamental and harmonic frequencies. The backshorts are arranged side by side between the input/output coupling arms, which makes for a very compact design with easy access to the tuner adjustments. Waveguide arms perpendicular to the tuner channels provide in-line input and output ports for multiplication or in-line signal and local oscillator (LO) ports for harmonic mixing. The mount is fabricated in two pieces, which are nearly mirror images of each other. The design is meant to be implemented with ordinary machining techniques — principally end-milling, sawing, or scribing the block halves. All six waveguide channels are in the same plane and no electroforming is required.

These waveguide mounts are particularly well-suited for circuits in which the electrically nonlinear elements are incorporated into stripline or suspended substrate circuitry rather than the more traditional, but circuit limiting, whisker-contact structures (although these can be accommodated as well). Both theoretical and experimental measurements of the mount indicate that the generic design enables matching over a wide range of impedances at both the fundamental and harmonic frequencies.

The figure shows the layout of a 110- to 220-GHz frequency doubler using the



The **Block Containing Waveguide Channels** and a few discrete components is one of two nearly-mirror-image blocks that are assembled to construct a frequency doubler.

new mount design. The overall dimensions of the block (with the two nearly-mirror-image block halves assembled) are 29 × 14 × 19 mm, where 14 mm is the distance between the input and output waveguide flanges. The 110-GHz input pump signal enters via a full height WR-8 waveguide (1.02 × 2.03 mm). The two opposing input tuner arms, which are also WR-8 waveguides, contain the noncontacting sliding backshorts, which provide series and parallel reactive tuning elements for matching at the input frequency. The backshorts are adjusted by use of micrometer heads. From the input tuner waveguide, the pump is coupled to a quartz microstrip probe, then along a microstrip harmonic separating filter to the multiplier diode, which is located across the output tuner waveguide. The filter is composed of chrome/gold low-pass elements on a fused substrate 0.152 mm thick and 0.33 mm wide. The distance between the input and output tuner waveguides is 2.50 mm. The filter extends beyond the output waveguide to allow additional electrical matching of both the input and output harmonic frequencies or possible idlers. In the doubler, the extended filter region provides an electrical short at the waveguide wall for both fundamental and second harmonic frequencies.

Output power leaves the block via an electric-field-plane waveguide arm perpendicular to the tuner arms. The output tuner waveguide, like the input, contains two noncontacting sliding backshorts, which provide series and parallel reactive matching elements at the output frequency of 220 GHz. The output impedance matching range is broadened by using reduced, rather than full, height waveguide (0.28 × 1.09 mm).

A built-in channel-waveguide-transformer brings the output guide up to standard height WR-4 (0.54 × 1.09 mm). The distances of the input and output port electric-field-plane arms from the input coupling probe and the multiplier diode are approximately one half of a guide wavelength at the respective center frequencies of operation. An additional filter, between the input/output tuner guides and perpendicular to the harmonic separating filter provides biasing capability for the diode. This filter ends in a wire bond to the center pin of an SMA coaxial connector which extends up from the bottom of the block.

This work was performed by Antti Raisanen, Debabani Choudhury, Robert J. Dengler, John E. Oswald, and Peter H. Siegel of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 4*** *on the TSP Request Card. NPO-19248*

Algorithm for Detecting dc Series Arcs

Load currents are analyzed to identify fluctuations characteristic of arcs.

Marshall Space Flight Center, Alabama

An algorithm has been developed for use in automatic detection of dc series arcs in power cables, cable terminations, and junction boxes. (The algorithm can also sometimes detect arcs inside electrical loads.) A system in which the algorithm can be utilized is one that receives its power from a microprocessor-based remote power controller that includes a load-current sensor. The algorithm analyzes the digitized load-current readings for fluctuations characteristic of dc series arcs.

An algorithm, as distinguished from something simpler, is needed for automatic detection of dc series arcs because the problem of identifying the arcs from load-current readings is not as simple as one might initially be inclined to think. A dc series arc is an arc that occurs whenever a switch carrying dc opens or a wire carrying dc ruptures. The arc continues until the arc current ceases to flow. Unlike an arc to ground (which is a short circuit and therefore easily detectable by conventional overcurrent-sensing circuitry), a dc series arc does not give rise to a large overcurrent; indeed, the current in a dc series arc can closely resemble normal current.

Experiments have shown that a dc series arc is characterized by a step (an increase or decrease, depending on the type of equipment) of typically about 8 percent in the load-current readings at the inception of the arc, followed by an increase in the noise component of the load current. The algorithm is based on this characteristic, and it works as follows: During the first few minutes of presumably normal operation, the digitized load-current readings are monitored to determine an initial background noise level. Thereafter, the monitoring continues, the background noise level is updated from time to time in coordination with the operation of the power-controlling microprocessor, and the noise level measured during each 10-ms interval is compared with the background level. A dc series arc is tentatively deemed to have begun whenever this short-term noise rises to several thousand times the background level during one 10-ms interval. Once an arc has thus been tentatively identified and for the next 300 ms, the number of 10-ms intervals during which this short-term noise exceeds 3 times the background noise level is counted. If the count exceeds 9, then the tentative identification is deemed to be confirmed.

Hazards that can be prevented by timely detection of dc series arcs include generation of smoke and poisonous gases, and ignition of nearby combustible materials. The algorithm has been optimized to reduce the false-alarm rate to about once per century. Of course, the algorithm offers no protection during the initial background-noise-monitoring interval.

This work was done by Greg L. Moores of Micon Engineering, Inc., for **Marshall Space Flight Center.** *For further information,* ***write in 71*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-26340.

Focal-Plane Analysis for Calculating Antenna Gain

Computation time is reduced substantially below that of the traditional method.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved method has been devised for calculating the gain of an antenna system that comprises a main reflector and an array of feed elements. In comparison with the traditional method, the improved method involves much less computation; this is an important advantage when it is necessary to compute gains repeatedly, with slight variations in design at each iteration, in an effort to find an optimum design.

In the traditional method, one calculates the gain from a perspective of transmission. One begins by calculating the current density produced on the reflector surface by each element of the array, then uses the classic radiation surface integral with an integrand proportional to [(current density) × (a direction-dependent phase factor)] to obtain the far electromagnetic field generated by the element. The gain is then calculated from the sum of the far fields generated by all of the elements. The calculation of far fields for all of the elements can consume much time; the amount of computation time can become prohibitive when it is necessary to perform the far-field calculations for evaluating a number of alternative geometric configurations for the array.

In the improved method, one calculates the gain from the perspective of reception, and it is not necessary to repeat the far-field calculation for each different geometric configuration of the array configuration. Instead, one computes a near reflected field that corresponds to a far field incident from a specified direction of reception, and it is necessary to perform this part of the calculation only once for each combination of reflector-surface configuration and receiving direction; it is not necessary to repeat this part of the calculation as long as the reflector-surface configuration and far-field direction remain the same.

The improved method is based on the Lorentz reciprocity theorem and, more particularly, on one of its consequences; namely, that the antenna gain in transmission or reception (they are the same) can be computed from a convolution of two fields in the focal plane of the reflector. One of these fields is the near field mentioned above; more specifically, the focal-plane field produced by a plane wave incident on the reflector from the specified direction of reception. The other field is the focal-plane field produced by the array of feed elements excited with currents in the specified amplitudes and phases.

This work was done by Paul W. Cramer, William A. Imbriale, and Sembiam R. Rengarajan of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 92*** *on the TSP Request Card.*
NPO-19460

Automated Monitoring of Dielectric Properties of Tree Trunks

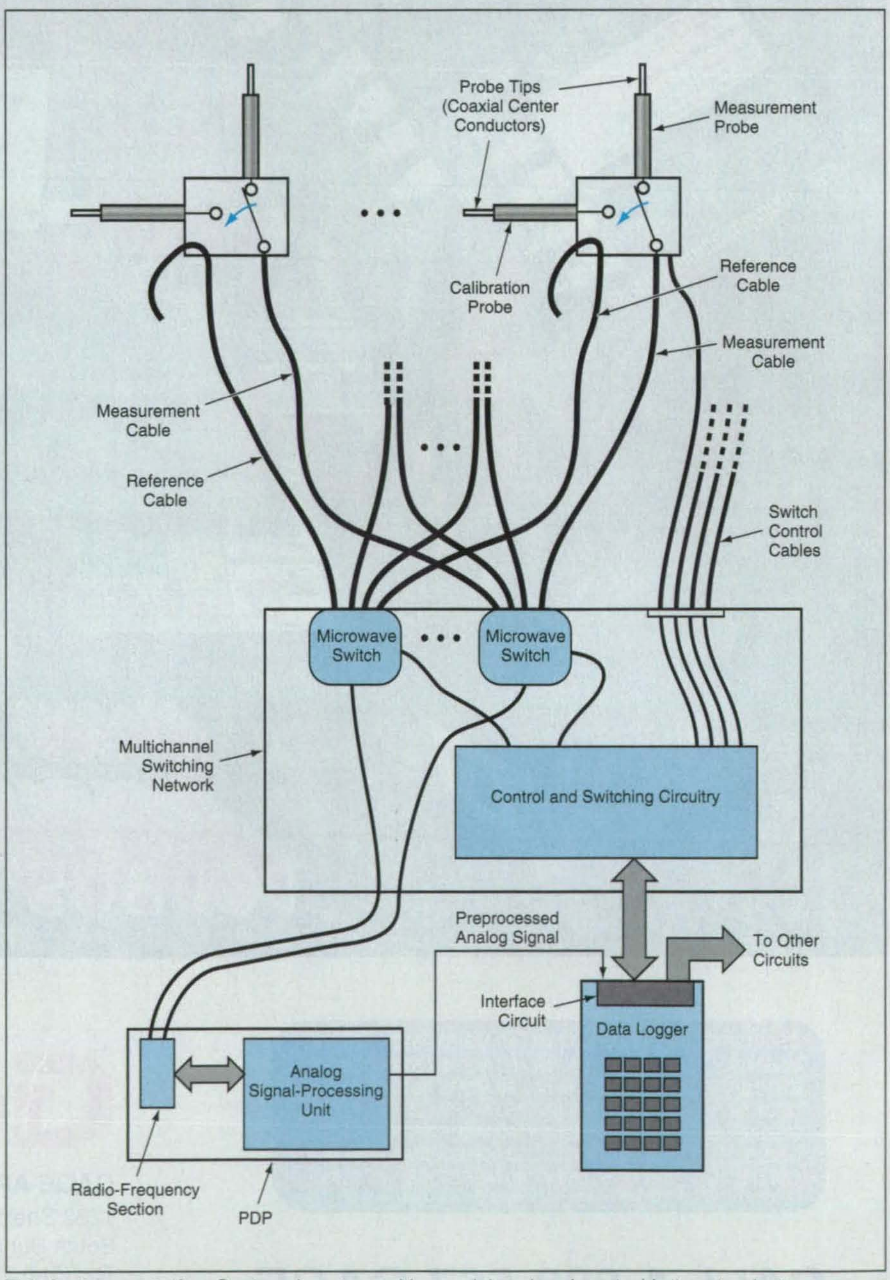
A semiautomated instrumentation system can be left unattended to monitor several trees.

NASA's Jet Propulsion Laboratory, Pasadena, California

A semiautomated instrumentation system called a "dielectric monitoring system" (DMS) has been developed for measuring the microwave permittivities of selected components of plants — in particular, of active xylems in tree trunks. The system is built around a modified version of a commercial instrument, called a "portable dielectric probe" (PDP), which includes a coaxial probe tip that is inserted into the xylem or other component to be monitored. The DMS includes eight measurement channels for nearly simultaneous monitoring of as many as eight trees. After being set up in the field, the DMS can be left unattended to record the measurement data; thus, the DMS makes it possible to perform continuous monitoring of time-varying dielectric properties of trees in remote forest regions, where previously, the labor-intensive nature of the measurements made such continuous monitoring impractical.

The design of the DMS incorporates the PDP into a complete monitoring system. The PDP operates in conjunction with a multichannel switching unit and a data logger (see figure). The PDP includes a radio-frequency section and an analog signal-processing unit that provide both the signals needed at the probe tips for measuring permittivities and a preprocessed analog signal for the data logger. The multichannel switching unit provides the multichannel monitoring capability and provides for automatic monitoring of a dielectric calibration reference (usually air) for each of the measurement channels. The data logger includes an interface circuit that automatically controls both the channel switching and a data-storage medium that can hold data from as many as 120,000 measurements. The data logger also includes a 12-bit analog-to-digital converter for high resolution of stored measurement data.

The center conductor of the coaxial probe tip is shown extended, whereas the center conductor of the coaxial probe tip of the unmodified PDP was flush with the flat end of the probe cylinder. The extension of the center conductor increases the reliability of contact between the probe and the specimen; it also increases the measurement volume, thereby providing greater measurement sensitivity plus assurance that the measurement samples the dielec-



This **Instrumentation System** is set up with coaxial probes inserted in tree trunks to measure dielectric properties. The system can be left to operate unattended to gather data on permittivities as a function of time.

tric properties throughout the active xylem or other layer to be probed.

Each measurement channel consists of a switch control cable and a pair of microwave cables, one of which is connected to a two-position microwave switch. The microwave switch is toggled between each of two coaxial probe tips. For each measurement channel, one measurement probe is mounted in the medium of interest, e.g., a tree trunk, while the other calibration probe is left exposed to the air to provide measurement of a reference material of known permittivity. The switch control cable allows for control of the microwave switch so that observations may be obtained from each of these two probe tips. The reference coaxial cable is the same electrical length as the measurement cable-switch-probe tip ensemble. This is required for the PDP to properly process the RF signal and determine the reflection coefficient observed at the probe tips.

This work was done by Kyle C. McDonald and William Chun of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 11*** *on the TSP Request Card. NPO-19338*

Modular, Hierarchical Learning by Artificial Neural Networks

Learning is streamlined by imitating some aspects of biological neural networks.

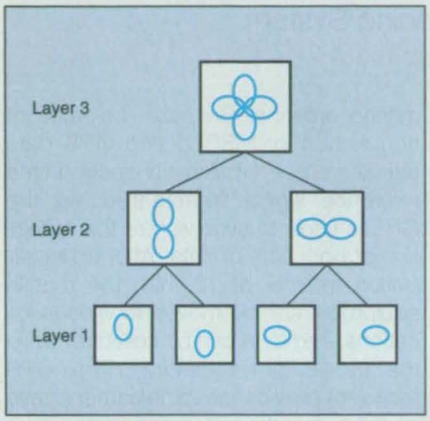
NASA's Jet Propulsion Laboratory, Pasadena, California

A modular and hierarchical approach to supervised learning by artificial neural networks is a subject of continuing research. This approach leads to neural networks that are more structured than are neural networks in which all neurons are fully interconnected. These networks utilize a general feedforward flow of information and sparse recurrent connections to achieve dynamical effects. The modular organization, the sparsity of modular units and connections, and the fact that learning is much more circumscribed than in networks of fully interconnected neurons are all attractive features for designing neural-network hardware.

Previous approaches to learning by artificial neural networks have involved, variously, the concepts of back-propagation of error signals and gradient descent of error measures in synaptic-connection-weight space. Although very powerful when applied to relatively simple problems, learning schemes based on these concepts alone break down as soon as sufficiently complex problems are considered. The modular, hierarchical approach was conceived to overcome this limitation.

This approach involves imitation of some aspects of learning schemes apparently followed by biological neural networks. Evolution seems to have overcome the obstacles inherent in gradient-descent learning. Learning in a biological neural network is never started from a tabula rasa. Rather, a high degree of structure is already present in the neural circuitry of a newborn organism.

Though little is known of the interaction between the prewired structure and the actual learning, it has been hypothesized that (1) complex learning tasks are broken up into simpler task modules that correspond to physical modules within a neural network, (2) learning, perhaps in different forms, can operate both within and across the gaps between modules, and (3) the modules can be organized in a hierarchical way. These hypotheses inspire the present modular, hierarchical approach.



The **Seven Modules** are connected sparsely in a hierarchical network designed to learn a double-figure-eight trajectory.

The modular, hierarchical approach has been demonstrated and tested by applying it to the problem of making a neural network learn planar trajectories like circles and figure eights. The modules in each higher level of the hierarchy control the outputs of the modules one level below. The modules at the lowest level of the hierarchy contain small numbers of relatively simple neural units that can be regarded collectively, in some sense, as an oscillator that learns some simpler component of the overall motion (e.g., a sinusoid, a circle, or a Fourier component). Each lowest-level module could be a simple oscillator ring with two or three neurons, an odd number of inhibitory connections, and sufficiently high gains.

The figure illustrates an example in which these concepts are applied to learning a trajectory that comprises two perpendicular figure eights. In this case, each of four lowest-level modules contains an oscillator ring that learns one of the four loops of the trajectory. The parameters of the neural components in the modules can be adjusted by gradient descent to make the loops match those of the desired trajectory.

The second level of the hierarchy in this example contains two control modules. Each of these modules controls a distinct pair of oscillator modules from the lowest level, so that it ends up producing a simple figure eight. Like the modules in the lower level, these modules can be oscillator rings and their parameters can be adjusted. In particular, after the learning process is completed, they should be operating in their high-gain regimes and the period of oscillation of each must equal the sum of the periods of the modules it controls.

The highest level of the hierarchy consists of another oscillatory and adjustable module that controls the two modules in the second level, so as to produce the double figure eight. This module must also end up operating in its high-gain regime. In general, the final output trajectory is a limit cycle because it is obtained by superposition of limit cycles of the various lower-level modules. If the various oscillators relax to their limit cycles independently of each other, it is essential to provide for adjustable delays between the various modules in order to get the proper harmony among the various phases.

In this way, a sparse network with 20 units or so can be constructed and made to execute a double figure eight.

This work was done by Pierre F. Baldi and Nikzad Toomarian of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 97*** *on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office–JPL; (818) 354-5179. Refer to NPO-19077.

Ground-Based Calibration of a Microwave Landing System

Reference data are acquired simultaneously from the Global Positioning System.

John F. Kennedy Space Center, Florida

A system of microwave instrumentation and data-processing equipment has been developed to enable ground-based calibration of a microwave scanning-beam landing system (MSBLS) at distances of about 500 to 1,000 ft (150 to 300 m) from the MSBLS transmitting antenna. The system is needed to ensure the accuracy of the MSBLS near the touchdown point, without having to resort to the expense and complex logistics of aircraft-based testing. In the original application for which this system was developed, the MSBLS to be calibrated is the one that gives primary landing guidance to the space shuttle orbiter during the final 20 miles (32 km) of approach. Modified versions of this system might prove useful in calibrating aircraft instrument landing systems.

As in the case of an aircraft-based system for calibrating the MSBLS at greater distances, the basic principle of this system is to use position data from the Global Positioning System (GPS) as references, with which the MSBLS position data are compared. However, instead of an MSBLS and a GPS receiver aboard an aircraft, this system includes an MSBLS and a GPS receiver installed in a trailer. The MSBLS and GPS receiving antennas are collocated at the top of a 50-ft (15-m) tower that is erectable from the trailer. Thus, the position of the collocated antennas simulates the position of a landing spacecraft or aircraft. To ensure the necessary precision of the GPS data, the system includes a GPS reference station located at a benchmark near the MSBLS transmitting antenna.

Once set up at the benchmark, the GPS reference station continues to receive signals from the GPS satellites, recording GPS code carrier-phase data throughout the calibration procedure. During the procedure, the MSBLS and GPS data received via the collocated antennas are recorded as the tower is positioned with a towing vehicle on and near the runway, at various distances and directions from the MSBLS transmitting antenna. Because the rates of acquisition of MSBLS and GPS data are different, a 1-pulse-per-second time reference signal transmitted via the GPS is used to synchronize the collection of both sets of data. After an initialization interval of 10 min, the mobile equipment can be moved to various locations, and data can be collected while the moves are underway. The GPS receivers provide real-time carrier phase position for the reference data, thus allowing the landing-system analysis to take place while acquiring the data.

This work was done by John J. Kiriazes, Marshall M. Scott, Jr., and Alfred D. Willis of **Kennedy Space Center** *and Temel Erdogan and Rolando Reyes of I-NET, Inc. For further information,* ***write in 40*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center; (407) 867-2544. Refer to KSC-11802.

Coherent-Phase Monitoring of Cavitation in Turbomachines

Vibration signals are processed to extract measures of cavitation.

Marshall Space Flight Center, Alabama

A digital electronic signal-processing system analyzes the outputs of accelerometers mounted on a turbomachine to detect vibrations characteristic of cavitation. It is desirable to detect and prevent cavitation in turbomachinery because cavitation can degrade performance, erode turbine blades, cause excessive structural vibrations, and eventually result in breakage.

The operation of this and older electronic cavitation-detection systems is based on a unique vibrational phenomenon associated with cavitation: when cavitation occurs in a rotary machine (e.g., a turbomachine), the wide-band noise generated by the collapse of cavitation bubbles becomes amplitude-modulated by the periodic components of motion associated with rotation (such as components at the fundamental frequency of rotation and its harmonics). This phenomenon gives rise to a periodicity in the accelerometer outputs; however, this periodicity is hidden in the sense that it is undetectable by ordinary linear spectral analysis.

Older cavitation-detection systems implement a technique called "full-wave rectification wide-band demodulation" (FWRWBD), which involves envelope detection of an isolated high-frequency band of an accelerometer output that includes a high-frequency, wide-band noise floor. The onset and existence of cavitation are determined by the recovery of periodicity in the detected signal, while the magnitude of the modulation is used to determine the severity

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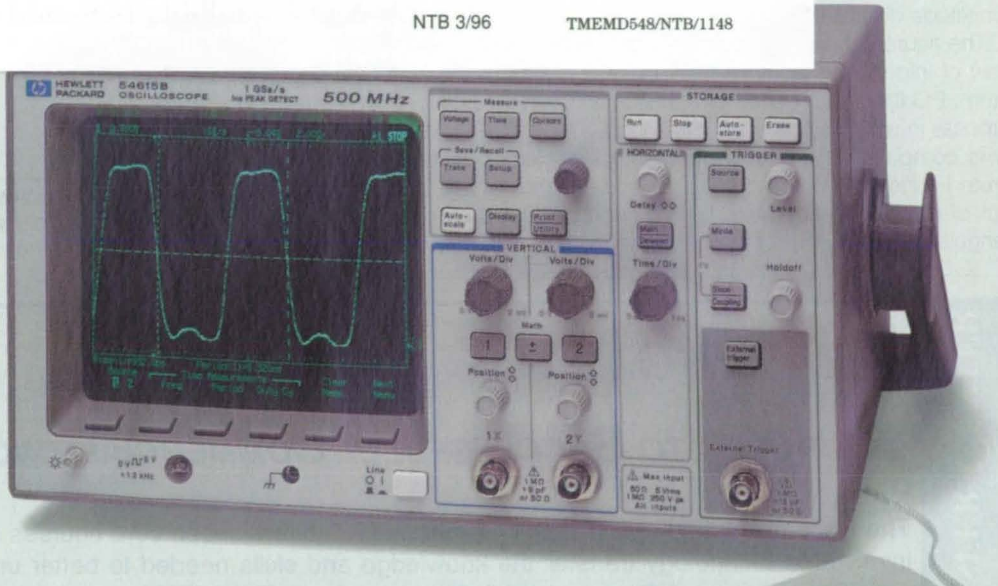

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of cavitation. Unfortunately, any discrete components (frequency components of structural vibrations) present in the high-frequency band in question give rise to peaks in the resulting demodulated signal. This limits the utility of FWRWBD in that it is difficult to distinguish between these peaks and signal peaks contributed by recovered hidden periodicity.

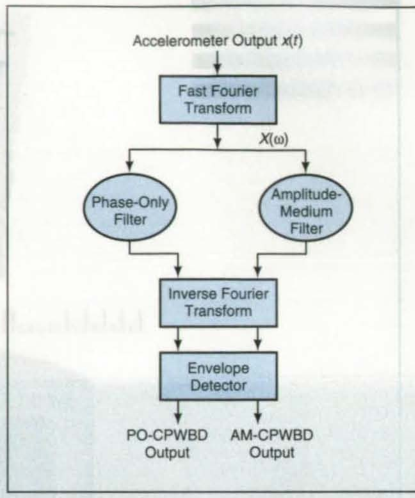
The present system is designed to overcome the limitation imposed by interference from discrete components. It is based on the discovery that cavitation can be identified solely by its hidden coherent-phase information. The system digitally implements a technique called "coherent-phase wide-band demodulation" (CPWBD), using phase-only (PO) filtering along with envelope detection to search for the unique coherent-phase relationship associated with cavitation and to minimize the influence of large-amplitude discrete components.

The figure schematically illustrates the flow of information in the CPWBD algorithm. PO filtering is performed prior to a process in which a power spectral density is computed in the form of (a) a discrete Fourier transform that is the product of (b) a frequency-band-limiting rectangular function and (c) the convolution of the discrete Fourier transform of the raw input signal with itself. The phase-only filter retains the coherent-phase relationship associated with the hidden periodicity that one seeks to identify. However, because of the amplitude-normalization effect of the phase-only filter, the system is no longer overwhelmed by independent discrete interference.

The amplitude of the hidden periodicity recovered via the PO part of the CPWBD algorithm is also subjected to some normalization. Therefore, the output of the PO part of the CPWBD algorithm should be viewed as a normalized "coherence" function for detecting the onset and existence of the wide-band-modulation (WBM) phenomena associated with cavitation. In order to detect the magnitude of the WBM signal and thereby gauge the intensity of cavitation, an "amplitude-medium" (AM) filter is introduced. This filter avoids the large vector-representation contribution of discrete interference while retaining the amplitude information about the degree of contribution toward the vector construction among various wide-band noise components. Therefore, the output of the AM part of the CPWBD algorithm should be viewed as a nonnormalized "spectrum" function for detecting the strength of the WBM signal associated with cavitation.

This work was done by Jen-Yi Jong of AI Signal Research, Inc., for **Marshall Space Flight Center.** *For further information,* ***write in 3*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-26313.



The **CPWBD Algorithm** recovers hidden periodicity, indicative of cavitation, from a noisy wide-band accelerometer output.

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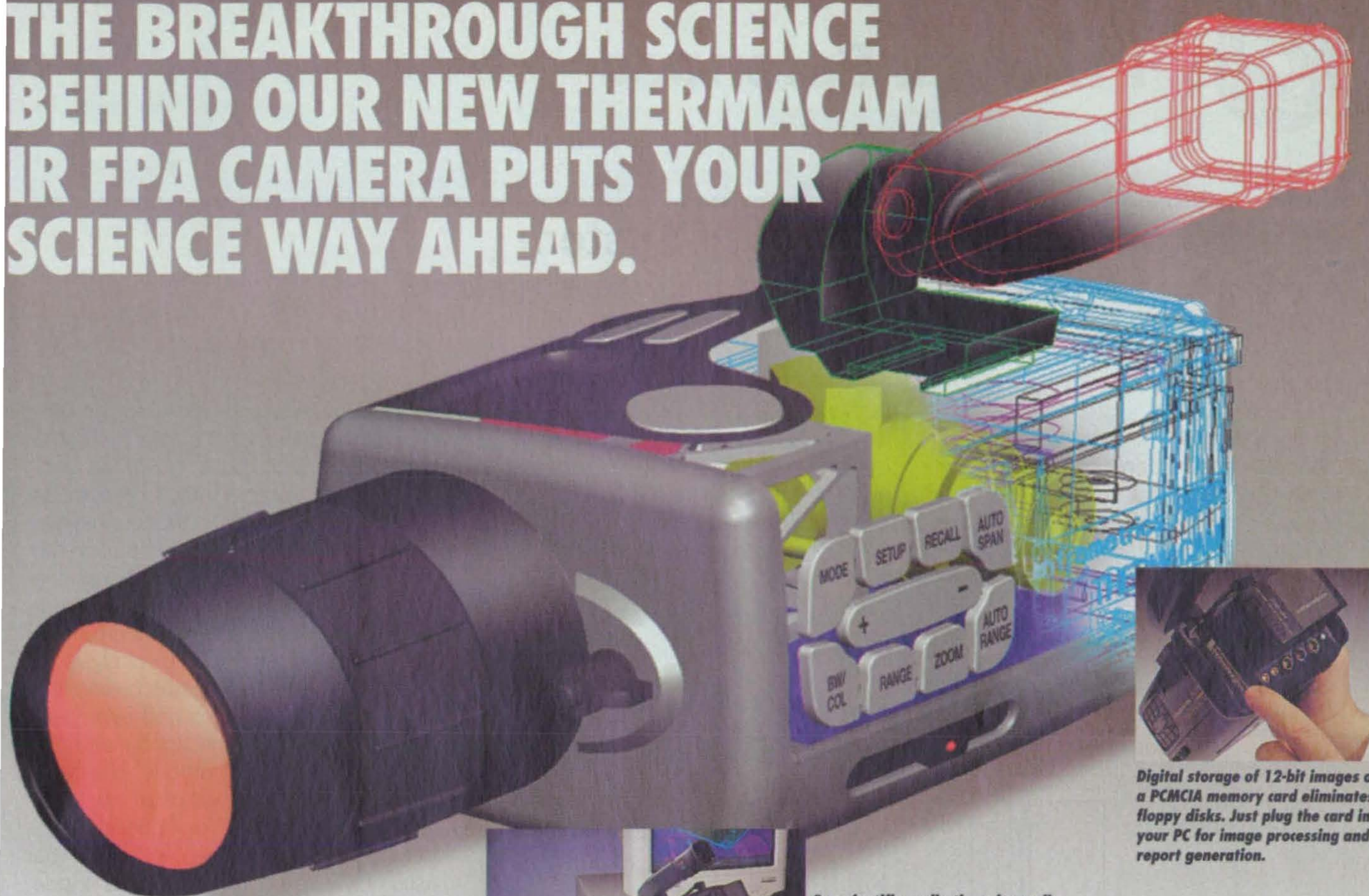

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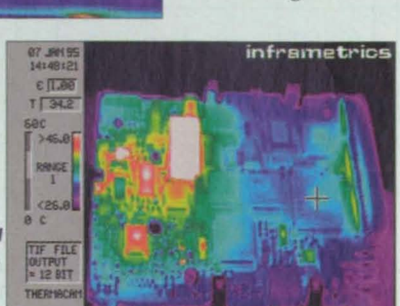

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Integrated Oxygen-Recovery System

A reactor converts carbon dioxide and water to oxygen and methane without emitting hydrogen.

Marshall Space Flight Center, Alabama

A developmental system for revitalizing breathing air in an enclosed environment converts carbon dioxide and water to oxygen and methane. These chemical conversions take place in a reactor module which contains a solid-metal-cathode water electrolyzer integrated with a Sabatier reactor. According to design estimates, a fully developed version of the system sized to maintain breathable air for four persons would occupy 67 percent less volume, weigh 60 percent less, and consume 3.4 percent less power than would a system of the same capacity but in which the electrolyzer and Sabatier reactor would be distinct components. Although oxygen is the primary desired end product in the system as originally contemplated, the product methane may also be of value in an industrial version of the system.

As in other systems, electrolysis of water in the reactor module breaks the water down into oxygen and hydrogen, the oxygen leaving the anode and the hydrogen leaving the cathode. The cathode is a tube that is part of an electrode assembly immersed in an aqueous electrolyte containing 55 percent KOH. The assembly also contains a porous anode that surrounds the cathode. A zirconia separator lies between the anode and the cathode (see Figure 1).

While still in monatomic form from the electrolysis, the hydrogen diffuses from the outside (electrolyte side) to the inside of the cathode tube, combining into hydrogen molecules at the interior surface. The hydrogen is used in the Sabatier reaction, in which carbon diox-

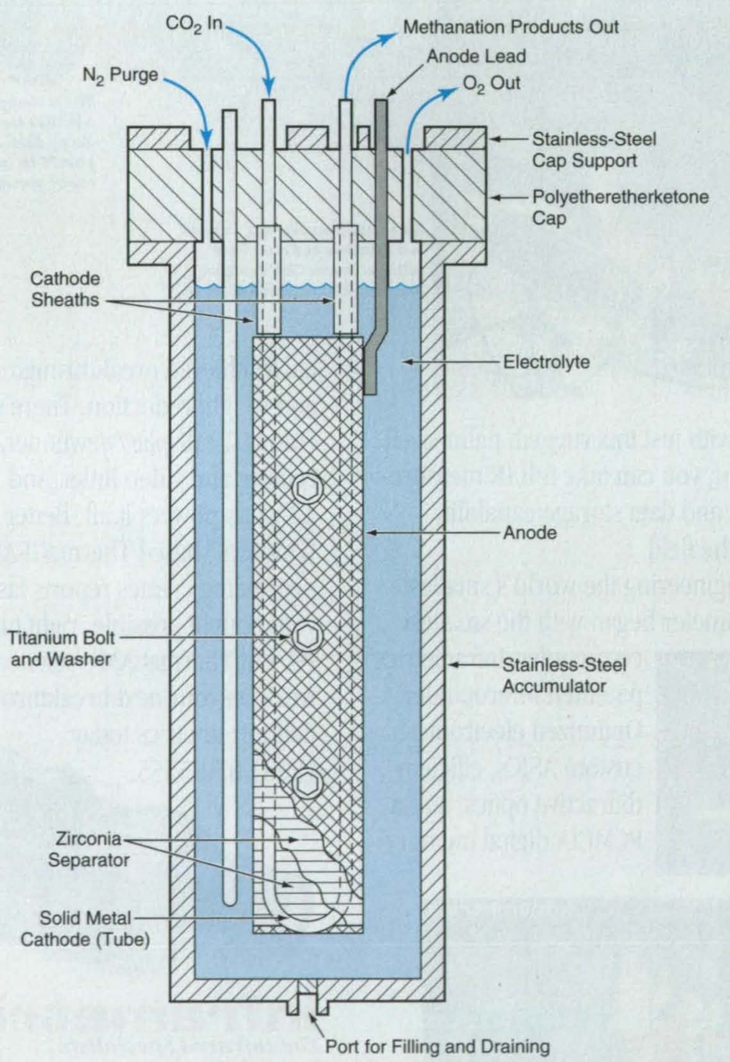

Figure 1. A **Reactor Module** in the integrated oxygen-recovery system features a simple, compact design. It contains both an electrolyzer and a Sabatier reactor.

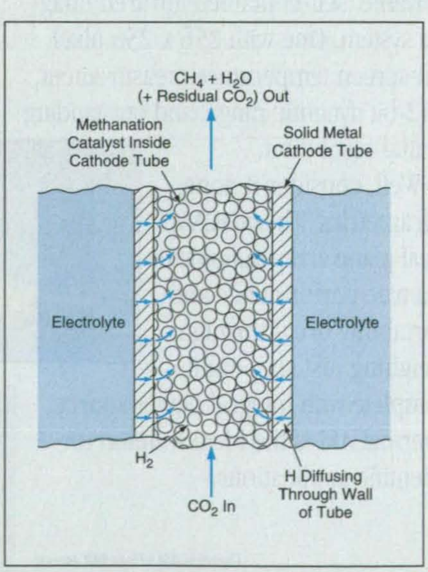

Figure 2. **Hydrogen From Electrolysis Diffuses** through the wall of the cathode into the interior space containing the methanation catalyst.

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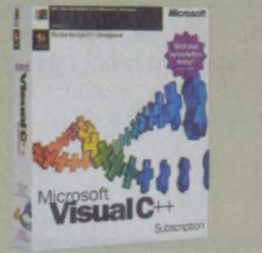

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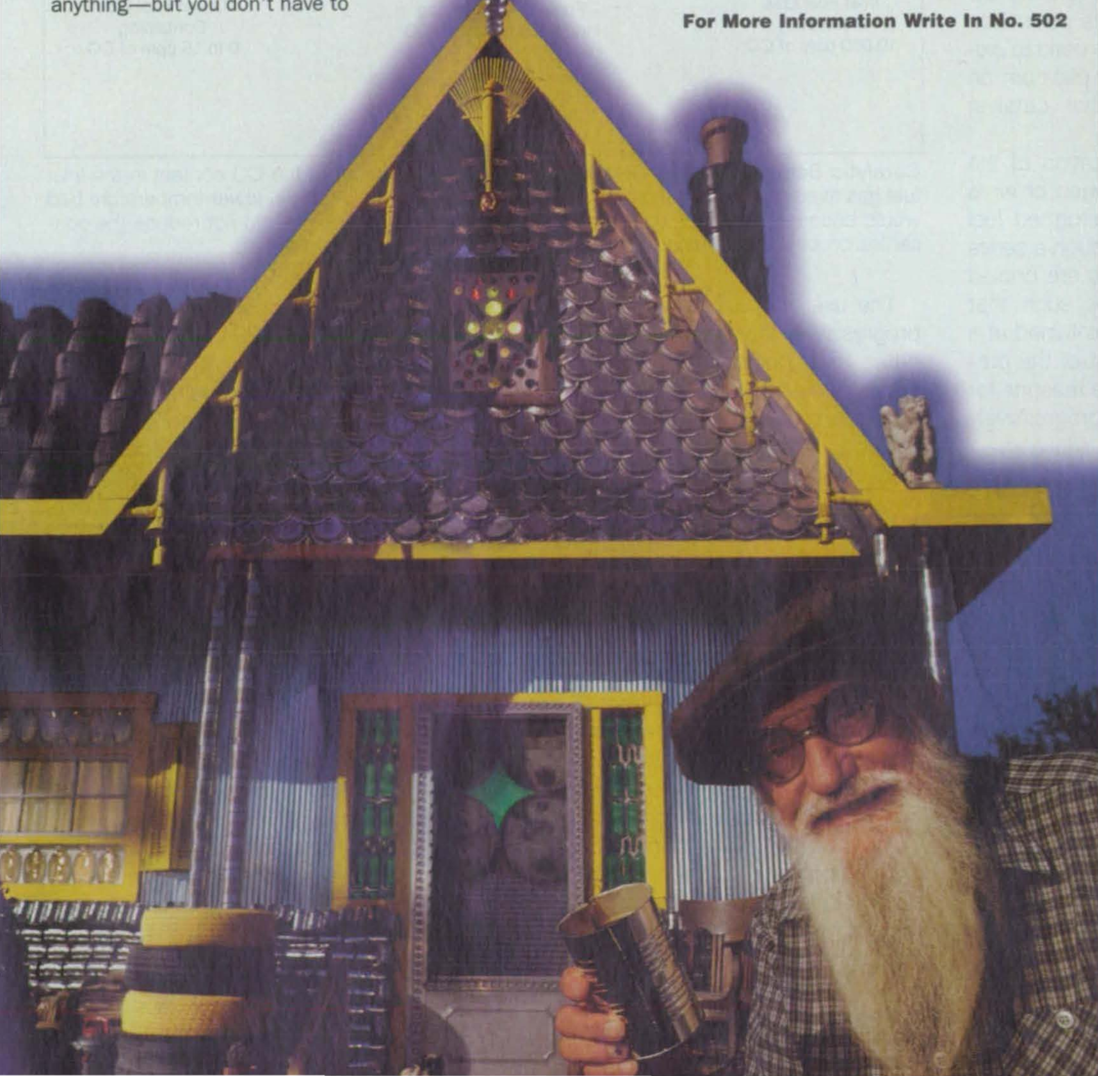

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ide and hydrogen react in the presence of a catalyst to form water and methane. Heretofore, the Sabatier reactor would have been a separate unit.

The advantages of this system arise from the placement of the methanation catalyst inside the cathode tube instead of in a separate reactor unit. This enables transfer of the hydrogen directly and nearly instantaneously from one reaction to the other, so that little or no free hydrogen leaves the reactor. Another advantage of this system is that the water consumed in the electrolysis is reclaimed in the Sabatier reaction. Yet another advantage is that even the heat generated by the Sabatier reaction can be used to help maintain an elevated reactor temperature that facilitates electrolysis. This reduces the power consumed by the electrolyzer. Besides the production of oxygen, the methane produced may be of commercial value.

This work was done by F. H. Schubert, R. J. Davenport, and M. G. Lee of Life Systems, Inc., for **Marshall Space Flight** *Center. For further information,* ***write in 38*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-26266.

Selective Oxidizer for Removal of Carbon Monoxide

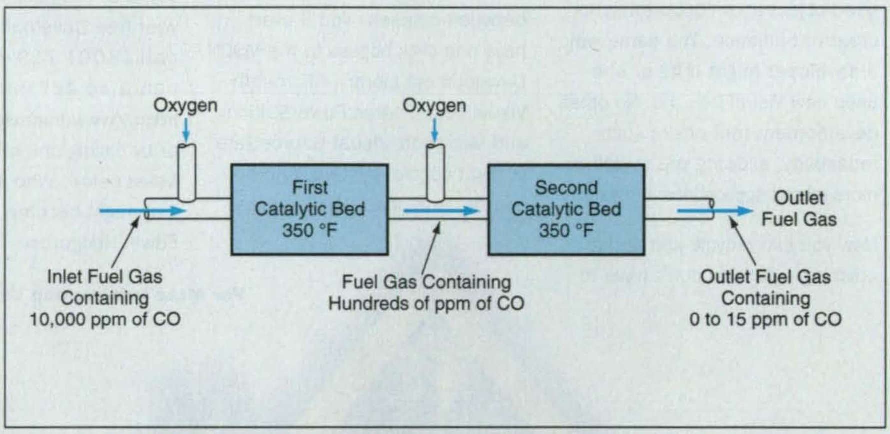
Multiple catalytic stages at progressively lower temperatures operate without becoming poisoned.

Lewis Research Center, Cleveland, Ohio

A catalytic apparatus selectively oxidizes most of the carbon monoxide (without also oxidizing the hydrogen) in a stream of reformed fuel gas that is fed to a low-temperature fuel cell. It is necessary to oxidize most of the carbon monoxide because the CO content of a typical stream of reformed fuel gas is of the order of 1 percent, whereas a low-temperature fuel cell cannot tolerate CO in concentrations ≥ 25 parts per million (ppm). Catalysts that can be used to oxidize CO selectively include platinum on alumina and a commercial catalyst known as "Selectoxo."

To provide for the oxidization of the CO, a small amount of oxygen or air is mixed into the stream of reformed fuel gas. The gas then flows through a series of catalytic beds. The beds are cooled under thermostatic control, such that each succeeding bed is maintained at a temperature lower than that of the preceding bed (see figure). The reasons for this staged operation at progressively lower temperatures are the following:

- A catalytic bed at a higher temperature [≈350 °F (177 °C)] typically reduces the level of CO levels from about 10,000 ppm (1 percent) to hundreds of ppm. Such a bed operates stably, with no increase in its outlet CO concentration with time. In other words, the catalyst in such a bed does not become poisoned by the CO.
- A catalytic bed at a lower temperature [≈170 °F (77 °C)] can initially reduce the concentration of CO from 10,000 ppm to 10 ppm. However, at this high inlet concentration of CO at the lower temperature, the bed is not stable in the sense that its outlet concentration of CO increases with time. In other words, the catalyst becomes passivated; that is, poisoned by the CO.



Catalytic Beds at Different Temperatures can oxidize most of the CO content in the inlet fuel gas stream for a long time without becoming poisoned. A single, lower-temperature bed would become poisoned, while a single, higher-temperature bed would not reduce the concentration of CO to an acceptably low level.

The use of multiple catalytic beds at progressively lower temperatures eliminates the poisoning. The first and hottest bed receives the highest concentration of CO (10,000 ppm) and enough oxygen to oxidize the CO. Because this bed operates at high temperature, it is not poisoned. This hottest bed reduces the concentration of CO from 10,000 ppm to hundreds of ppm.

With its lower CO content, the stream of gas is then fed to a cooler bed, along with more oxygen. In the cooler bed, the CO content is reduced from hundreds of ppm to a level between 0 and 15 ppm. Because the gas that enters the second bed contains much less CO than does the gas that enters the first bed, the second bed is less susceptible to poisoning by CO and its life is extended accordingly.

This concept has been verified by an experiment on a prototype of the apparatus containing two catalytic beds. The first bed was operated at 350 °F (177 °C) with 1 percent of CO in the inlet gas. The second bed was operated at 170 °F (77 °C). At the end of 330 h, the concentration of CO at the outlet from the first bed and the inlet for the second bed was 275 ppm, and the concentration of CO at the outlet of the second bed was 6 ppm. In contrast, the concentration of CO at the outlet of a single catalytic bed operating with an inlet CO concentration of 1 percent at a temperature of 170 °F (77 °C) increased from an initial level of 5 ppm to a level of 60 ppm after 135 h.

This work was done by John C. Trocciola, Craig R. Schroll, and Roger R. Lesieur of International Fuel Cells Corp. for **Lewis Research Center**. *For further information,* ***write in 66*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center; (216) 433-2320. Refer to LEW-15630.

Silicon Carbide Transistor for Detecting Hydrocarbon Gases

A porous gate would allow passage of gas molecules.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed silicon carbide variable-potential insulated-gate field-effect transistor would be specially designed for use in measuring concentrations of hydrocarbon gases. Devices like this one should prove useful in numerous automotive, industrial, aeronautical, and environmental monitoring applications.

The device (see figure) would include a sensing gate that would comprise an open-metal-grid electrical contact (such as chromium) on a layer of porous undoped SiC that has been photo-electrochemically etched in a 6H-SiC wafer. The pores in the undoped SiC layer would be oriented perpendicular to the top of the device by the etching process. The sensing gate would lie on an aluminum nitride insulating layer on top of a layer of n^+-doped SiC mounted on a suitable dielectric support. Drain and source contacts would be attached to the n^+ layer, and a variable potential contact would be attached to the metal grid.

Hydrocarbon gas molecules would diffuse through the open metal grid into the porous SiC layer, where they would be adsorbed onto the surfaces of the pores. The hydrocarbon-gas sensor operates by dissociating or electrochemically oxidizing these hydrocarbons adsorbed to the inner surfaces of the SiC detection layer formed by the porous SiC. Dissociation or oxidation reactions are driven by a varying potential applied to the detection layer. Different hydrocarbon species undergo these reactions at different applied potentials so that the device is able to discriminate among various hydrocarbon species. Hydrogen ions produced by the dissociation reactions would travel to the surface of the aluminum nitride insulating layer, giving rise to an electric field that would, in turn, result in a depletion layer in the n^+-doped SiC channel on the opposite side of the insulator. As in other field-effect transistors, the magnitude of this electric field and thus the extent of the depletion layer would affect the amount of current flowing between the source and drain.

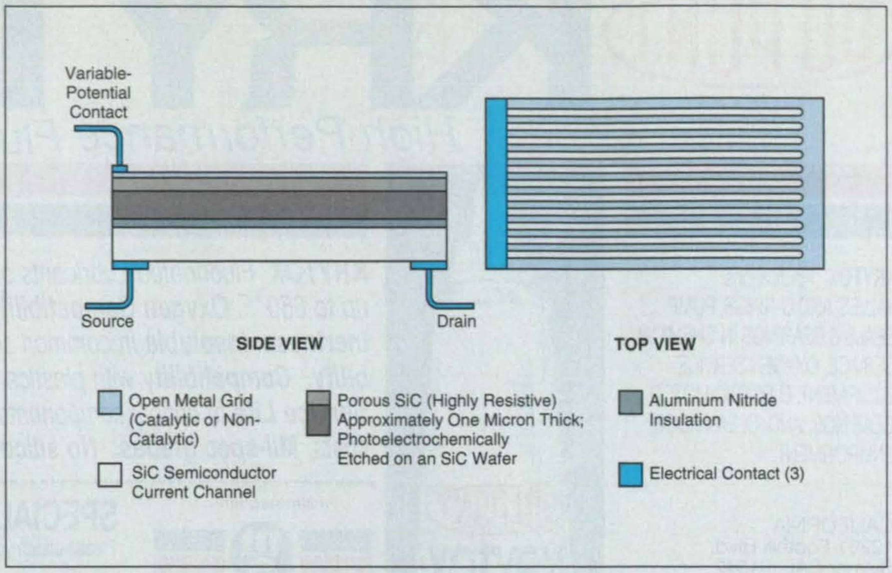
The device can operate at temperatures between 100 °C and at least 600 °C, allowing hydrocarbon detection in hot exhaust gases. The dissociation reaction is detected as a change in the current flow through the transistor. The SiC detection layer can be augmented by replacing the metal grid with one composed of a catalytic metal, which provides a signal without an applied potential at higher operational temperatures. Comparisons between the catalytically produced signal and the varying-potential produced signal may further help identify the hydrocarbons present.

The magnitude of the variable potential on the porous SiC layer would be a measure of the strength of the molecular bond that could be broken by the applied electric field. Thus, to the extent to which the strengths of molecular bonds could be used to distinguish among chemical species, the applied potential needed to obtain a nonzero reading could be taken as an indication of the detected molecular species. The magnitude of the current in the source-to-drain channel would indicate the concentration of the species.

The number of molecules adsorbed on the surfaces of the pores could eventually become excessive. In that case, the potential applied to the variable-potential contacts would be reversed and increased to drive off the adsorbed molecules.

A prototype sensor composed of the gate structure of the transistor has been fabricated and is undergoing tests. Preliminary results have demonstrated an ability to discriminate between inert gases and hydrocarbon gases such as methane and propylene from about 100 °C to 400 °C.

This work was done by Virgil B. Shields, Margaret A. Ryan, and Roger M. Williams of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 74*** *on the TSP Request Card.*



Bond Breakage due to dissociation and electrochemical oxidation in the pores of the porous SiC layer would generate ions, which would migrate to the surface of the aluminum nitride. There, the electric field generated by the accumulated ions would affect the transistor current according to the basic principle of operation of a field-effect transistor.

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office–JPL; (818) 354-5179. Refer to NPO-19428.

Swivel Total-Temperature Probe

A probe aligns itself with airflow to measure total temperature at high angle of attack.

Dryden Flight Research Center, Edwards, California

Figure 1 illustrates a swivel total-temperature probe. This is an improved probe designed to be mounted at the wingtip of an airplane and to be used for measuring the total temperature of the air when the airplane flies at high angles of attack.

Flight at high angles of attack has recently become more popular in the fighter community for its potential in tactical maneuvering. Current total-temperature probes on fighter aircraft were not designed for flight at high angles of attack. A total-temperature measurement is combined with a mach number to compute the ambient temperature, which is

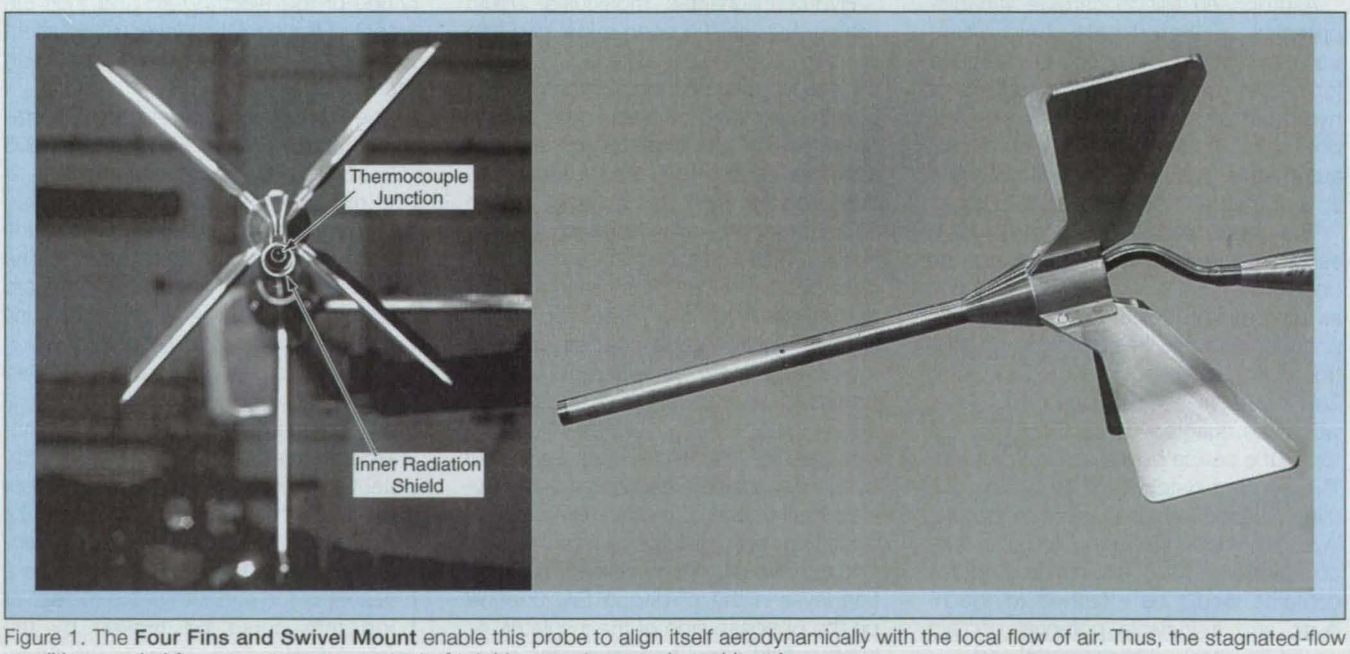


Figure 1. The **Four Fins and Swivel Mount** enable this probe to align itself aerodynamically with the local flow of air. Thus, the stagnated-flow condition needed for accurate measurement of total temperature can be achieved.

necessary for computing the true airspeed and Reynolds number. It is questionable whether total-temperature measurements at high angles of attack will be necessary on production fighters because control laws and flight-operation decisions are typically based on mach number, calibrated airspeed, or equivalent airspeed; none of these quantities depends on measurement of total temperature. However, true airspeed and Reynolds number are of interest to the flight-research community. Consequently, there was a need to develop a total-temperature probe for flight research at high angles of attack.

A standard total-temperature probe is potentially subject to large errors at high angles of attack because (1) its orientation is fixed and thus cannot be adjusted to stagnate the flow (as is necessary for measuring total temperature) at high angles of attack and (2) deicing heat at the low airspeeds associated with high angles of attack can distort probe readings. When using a fixed total-temperature probe, errors of the first-mentioned type can be mitigated by mounting the probe on the underside of the fuselage to take advantage of a flow-straightening effect of the fuselage at high angle of attack, while errors of the second-mentioned type can be mitigated only by turning off deicing heaters.

The swivel probe, which does not contain deicing heaters, was designed to align itself aerodynamically with the local airflow. The swivel total-temperature probe includes a type-K (Chromel/ Alumel) thermocouple within an inner radiation shield embedded in a tube similar to a pitot-tube on a wingtip-mounted air-data boom.

The performance of the swivel total-temperature probe has been evaluated in flight tests at the NASA Dryden Flight Research Center, using the F-18 High Alpha Research Vehicle (HARV). Excellent results have been achieved in dynamic flight at angles of attack as large as 70°. At the time of submission of information for this article, seventy flights had been completed, with no structural or instrumentation failures.

The data plotted in Figure 2 include results for a fairly dynamic high-angle-of-attack pushover/pullup maneuver. Ambient-temperature profiles from a fuselage-mounted fixed probe, the swivel probe, and a standard-day calculation are shown. The swivel-probe data have been adjusted for an instrumentation bias, the cause of which has not yet been ascertained. The data obtained from the swivel total-temperature probe follow the trends of the standard-day temperature profile much more closely than do the data from the fixed probe. The errors in the fixed-probe data include the high-angle-of-attack and deicing-heat errors mentioned above. Inasmuch as the flow-straightening effect of the F-18 fuselage mitigates much of the high-angle-of-attack error, a major part of the fixed-probe error is attributed to deicing heat. Also shown in Figure 2 is a plot of the difference between the true airspeeds computed from temperature readings of the fixed and swivel probes during the maneuver in question. The magnitude of the difference was as much as 25 ft/s (7.6 m/s), which is approximately 8 percent of the true airspeed.

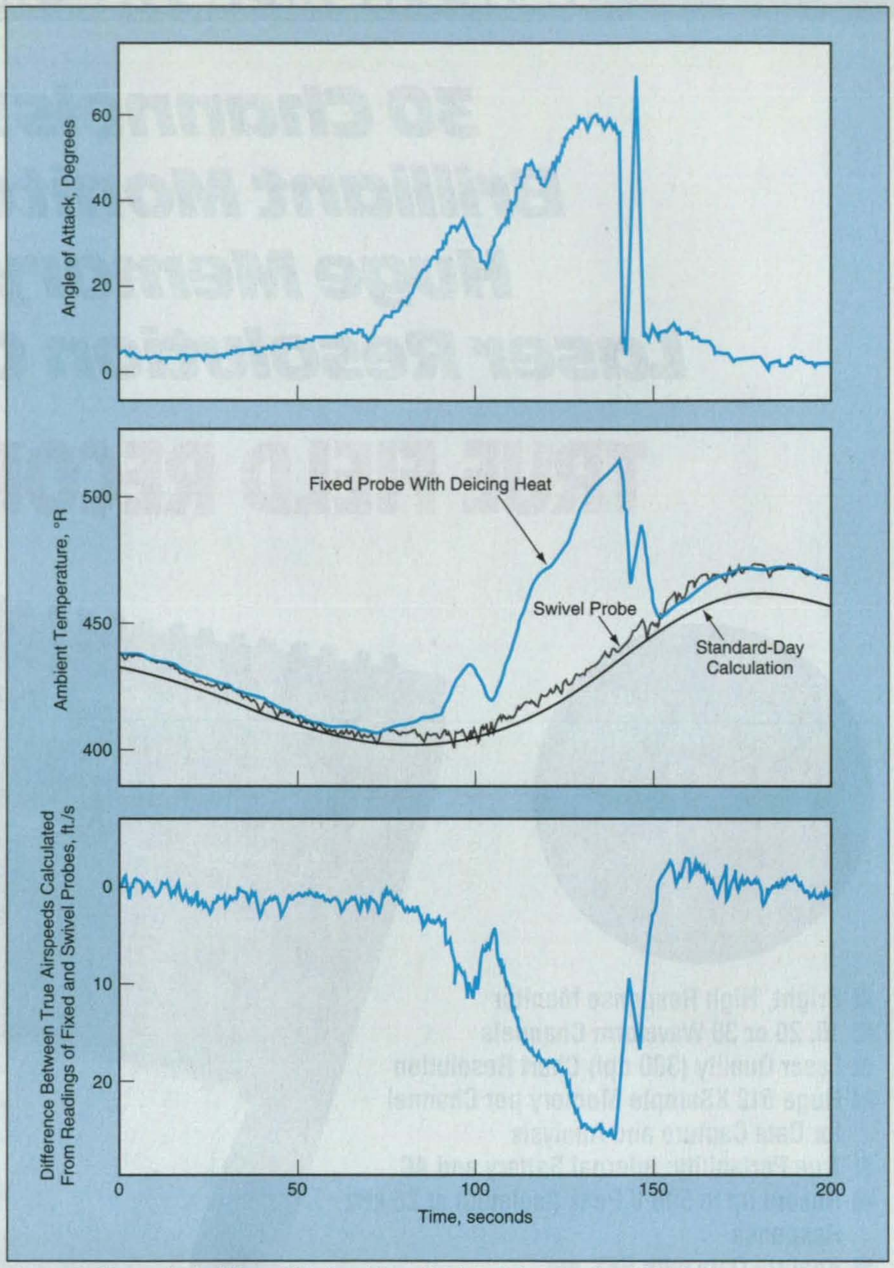


Figure 2. **These Data Were Obtained** in a flight test that involved highly dynamic maneuvering at high angles of attack.

These results are preliminary. Work is continuing in an attempt to (1) understand the cause of the bias in the swivel-probe temperature measurements and (2) document the accuracy of the swivel-probe measurements at numerous static and dynamic flight conditions that involve high angles of attack. The fixed total-temperature probe works remarkably well at high angles of attack with the deicing heater turned off; if such operation is allowable, flight-research data of acceptably high quality can be obtained by use of a fuselage-mounted fixed total-temperature probe.

This work was done by Tim Moes, Doug Nichols, Dirk Vanderloop, and Rich Rood of **Dryden Flight Research Center**. *For further information, make contact with Tim Moes by electronic mail at moes@wilbur.dfrc.nasa.gov. DRC-95-21*

Testing Thermophotovoltaic Cells With Black-Body Radiation

Test conditions can be varied conveniently and are reproducible.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of testing thermophotovoltaic (TPV) cells involves maintaining the cells at various temperatures while exposing the cells to black-body radiation at various intensities from black-body sources at various other temperatures. This method provides for simulation and evaluation of performance under a variety of operating conditions and could thus become a standard testing method for government and industry.

In a TPV apparatus, heat is first converted into photons via a thermal emitter, and these photons in turn are converted to electricity via TPV cells, which are similar to ordinary photovoltaic cells except that they are fabricated to have a bandgap that corresponds to the peak of the spectrum of radiation from the thermal emitter. In principle, the energy-conversion efficiency of such an apparatus can exceed that of a conventional photovoltaic cell if the apparatus comprises a thermal emitter of high emissivity and bandgap-matched TPV cells.

Heretofore, testing of TPV cells has involved measuring their current-vs.-voltage responses during irradiation from lamps or from selective emitters. Such tests have revealed little about performances of cells under various operating conditions because the test conditions (emission temperature and/or emission spectrum, emission intensity, and cell temperature) have rarely been varied. Furthermore, such tests have not been reproducible because the emission temperatures and/or spectra have been incompletely characterized and highly specific to the thermal emitters used.

The present method overcomes these limitations, providing both variability and reproducibility. The black-body spectrum is characterized by Planck's equation and is easily reproducible with a standard black-body emitter. A black-body emitter can be set at various emission temperatures, thus altering the spectrum of the emission as needed to test TPV cells. The intensity of black-body radiation incident on a TPV cell under test can be varied by simply placing the cell at various distances from the black-body emitter. Because the black-body spectrum is known, the results of tests at various emission temperatures and intensities can be used to predict responses of TPV cells to radiation from non-black-body sources.

This work was done by James J. Lin and Dale R. Burger of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 68*** *on the TSP Request Card.*
NPO-19333

Skutterudite Compounds for Power Semiconductor Devices

These materials exhibit high hole mobilities, high doping levels, and high electronic figures of merit.

NASA's Jet Propulsion Laboratory, Pasadena, California

New semiconducting materials with *p*-type carrier mobility values much higher than those of state-of-the-art semiconductors have been discovered. The nine compounds, antimonides $CoSb_3$, $RhSb_3$, $IrSb_3$, arsenides $CoAs_3$, $RhAs_3$, $IrAs_3$, and phosphides CoP_3, RhP_3 and IrP_3, exhibit the same skutterudite crystallographic structure and form solid solutions of general composition $Co_{1-x-y}Rh_xIr_yP_{1-w-z}As_wSb_z$. Some of these compositions have shown great potential for application to thermoelectric devices.

There are also a number of more complex skutterudite compositions including solid solutions and ternary compounds. This family of semiconducting materials offers great potential for utility in (a) high-frequency power-semiconductor devices like power field-effect transistors, (b) these and other electronic devices at temperatures above 150 °C where Si cannot be used, and (c) other electronic devices (e.g., tunnel diodes and lasers) made of heavily doped materials. These skutterudite compounds are relatively easy to prepare, and some of them are reasonably inexpensive. Provided lower carrier concentrations can be achieved for these new materials, they might even challenge current state-of-the-art lightly-doped electronic materials used in a variety of junction devices.

The antimonides $CoSb_3$, $RhSb_3$, $IrSb_3$, and arsenides $CoAs_3$ and $RhAs_3$ all exhibit semiconducting behavior, with band-gap values ranging from 0.63 to 1.18 eV. The phosphide compounds, currently under investigation, are expected to have even wider band gaps. Due to the exceptionally high hole mobilities, *p*-type skutterudites exhibit high electrical-conductivity values ranging from 2 to $5 \times 10^5\ \Omega^{-1}\ m^{-1}$ for a hole concentration of $1 \times 1025\ m^{-3}$.

The room temperature mobility values of *p*-type skutterudites are 1 to 100 times higher than that for *p*-type Si and GaAs at similar carrier concentrations, as seen in the first figure. $RhSb_3$ exhibits

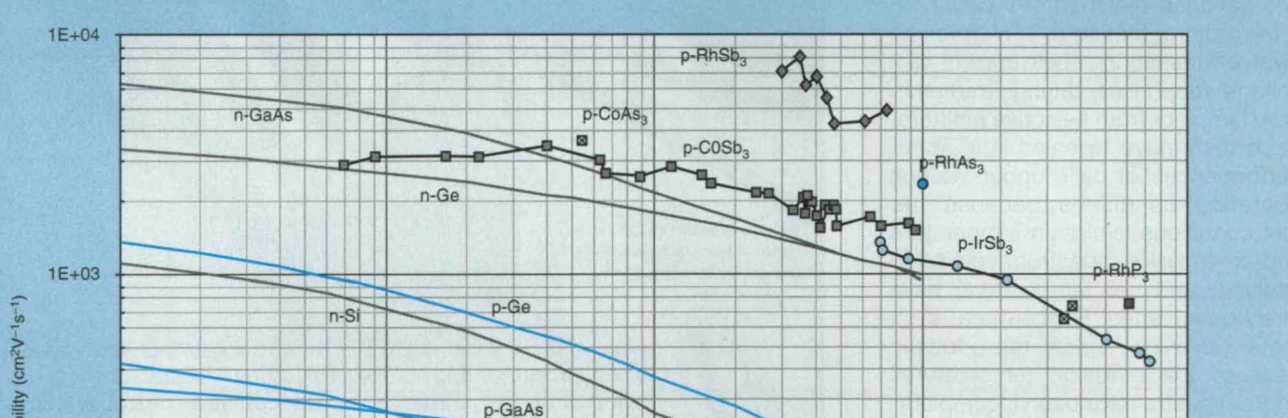


Figure 1. In **Hall Mobility Versus Carrier Concentration** at 300 K for *p*-type skutterudite compounds, data are compared to *n*-type and *p*-type state-of-the-art electronic materials. (*N*-type $CoSb_3$ data are also included.)

the greatest hole mobility, 8000×10^{-4} $m^2V^{-1}s^{-1}$ for a carrier concentration of 2.5×10^{24} m^{-3}, which is about 70 times higher than *p*-type GaAs and still 5 times higher than *n*-type GaAs. Skutterudites with *n*-type conductivity can be obtained by doping with selected elements. The electron mobilities of *n*-type $CoSb_3$ are comparable to the values obtained for *p*-type Si and GaAs. Due to the preparation techniques used thus far, skutterudite samples with carrier concentration $< 7.0 \times 10^{22}$ cm^{-3} have not yet been obtained, but it is expected that the carrier mobility will increase with decreasing carrier concentrations. The temperature dependencies of the carrier mobilities of the skutterudites also compare favorably with those of state-of-the-art semiconductors. Even at 550 °C, the hole mobility of $IrSb_3$ has been observed to be about 600×10^{-4} $m^2V^{-1}s^{-1}$ for a carrier concentration of 6.5×10^{24} m^{-3} — about 4 times the value obtained for *n*-type Si.

The second figure shows the power semiconductor figures of merit for *p*-type skutterudites and *n*-type state-of-the-art semiconductors Ge, Si, and GaAs calculated for a carrier concentration of 1×10^{25} m^{-3}. This graph demonstrates that the high mobilities at high doping levels of the *p*-type skutterudites more than offset their low thermal-conductivity values (one fourth of GaAs), even when comparing to the high electron mobility *n*-type state-of-the-art electronic materials. This means that the temperature rise of junctions above ambient temperature will be negligible, minimizing heat dissipation problems. Also, the mobilities of the skutterudites decrease slowly with temperature, and this raises the possibility of operating electronic devices at temperatures much higher than possible when using devices made of Si.

This work was done by Jean-Pierre Fleurial, Thierry Caillat, Alexander Borshchevsky, and Jan Vandersande of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 94*** *on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

William T. Callaghan, Manager
Technology Commercialization
JPL-301-350
4800 Oak Grove Drive
Pasadena, CA 91109

Refer to NPO-19378, volume and number of this NASA Tech Briefs *issue, and the page number.*

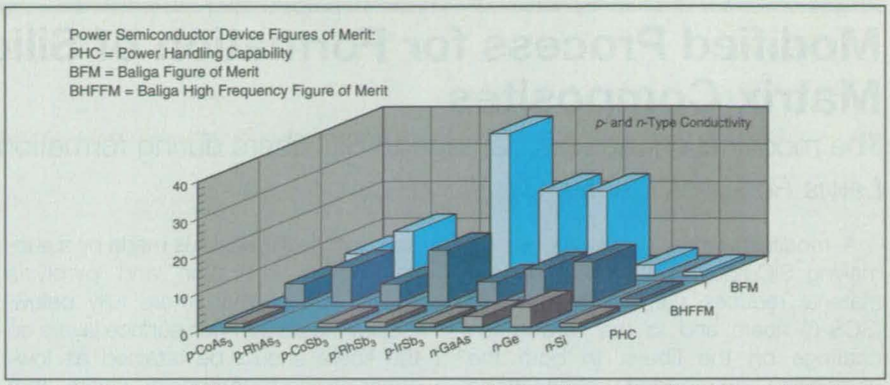


Figure 2. **Figures of Merit** are shown for *p*-type skutterudite and state-of-the-art electronic materials for power semiconductor devices. (All data for a carrier concentration of 1×10^{19} cm^{-3} are normalized to *n*-type Si.)

For More Information Write In No. 413

Modified Process for Formation of Silicon Carbide Matrix Composites

The modification reduces damage to SiC fibers during formation of an SiC matrix.

Lewis Research Center, Cleveland, Ohio

A modified version of a process for making SiC-fiber/SiC-matrix composite material reduces damage to the SiC (SCS-6) fibers and to the carbon-rich coatings on the fibers. In both the unmodified and modified versions of the process, the matrix material that surrounds the fibers is reaction-formed silicon carbide (RFSC); it is made by a succession of infiltration and pyrolysis steps, as explained more fully below. Ideally, the carbon-rich surface layers on the fibers should be retained as low-shear-strength interfacial layers that make the composite less brittle. In the unmodified process, these carbon-rich layers are destroyed and the underlying SiC fibers are damaged, also as explained more fully below.

In both the unmodified and modified versions of the process, the first step is to infiltrate a stack of SiC fiber mats with a liquid polymer-forming mixture that comprises a high-char-yield monomeric resin, a pore-forming agent, a curing agent, and carbon powder filler. The mixture is cured to encase the fiber mats in a porous polymer matrix. The resulting composite intermediate product is heated to drive off the pore-forming agent and pyrolyze the matrix to a porous carbon char.

In the unmodified version of the process, the next step is to infiltrate the porous carbon matrix with liquid silicon or a silicon alloy. The liquid silicon or silicon alloy reacts with the carbon matrix to form a matrix of mostly silicon carbide with other phases mixed in. Unfortunately, the liquid silicon also reacts with the carbon-rich surface layers on the SiC fibers, consuming those layers and attacking the underlying SiC fiber material. Such attack can be prevented by use of protective coats on the SiC fibers, but of course, protective coating increases the cost.

In the modified version of the process, the damage to the SiC fibers is reduced, without need for protective coating. The modification consists of the addition of a second polymer-infiltration-and-pyrolysis step to increase the carbon content of the porous matrix before infiltration with liquid silicon or silicon alloy. The polymer-forming mixture used in this step is similar to that used in the first step except that it does not contain carbon powder. Next, the matrix is infiltrated with liquid silicon or silicon alloy. As before, the silicon reacts with the carbon matrix material to form a silicon carbide matrix, but in this case, the silicon carbide fibers and their carbon-rich surface layers remain intact.

This work was done by Donald R. Behrendt of **Lewis Research Center** *and Mrityunjay Singh of NYMA, Inc. For further information,* ***write in 41*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center; (216) 433-2320. Refer to LEW-15690.

Epitaxial Silicon Doped With Antimony

High purity can be achieved in layers of arbitrary thickness.

NASA's Jet Propulsion Laboratory, Pasadena, California

High-purity epitaxial silicon doped with antimony can be made by chemical vapor deposition, using antimony pentachloride ($SbCl_5$) as the source of dopant and SiH_4, $SiCl_2H_2$, or another conventional source of silicon (see figure). Epitaxial silicon doped with antimony is needed to fabricate impurity-band-conduction photodetectors that operate at wavelengths from 2.5 to 40 μm; in contrast, impurity-band-conduction photodetectors previously made from silicon doped with arsenic operate in the narrower wavelength range of 2.5 to only 28 μm.

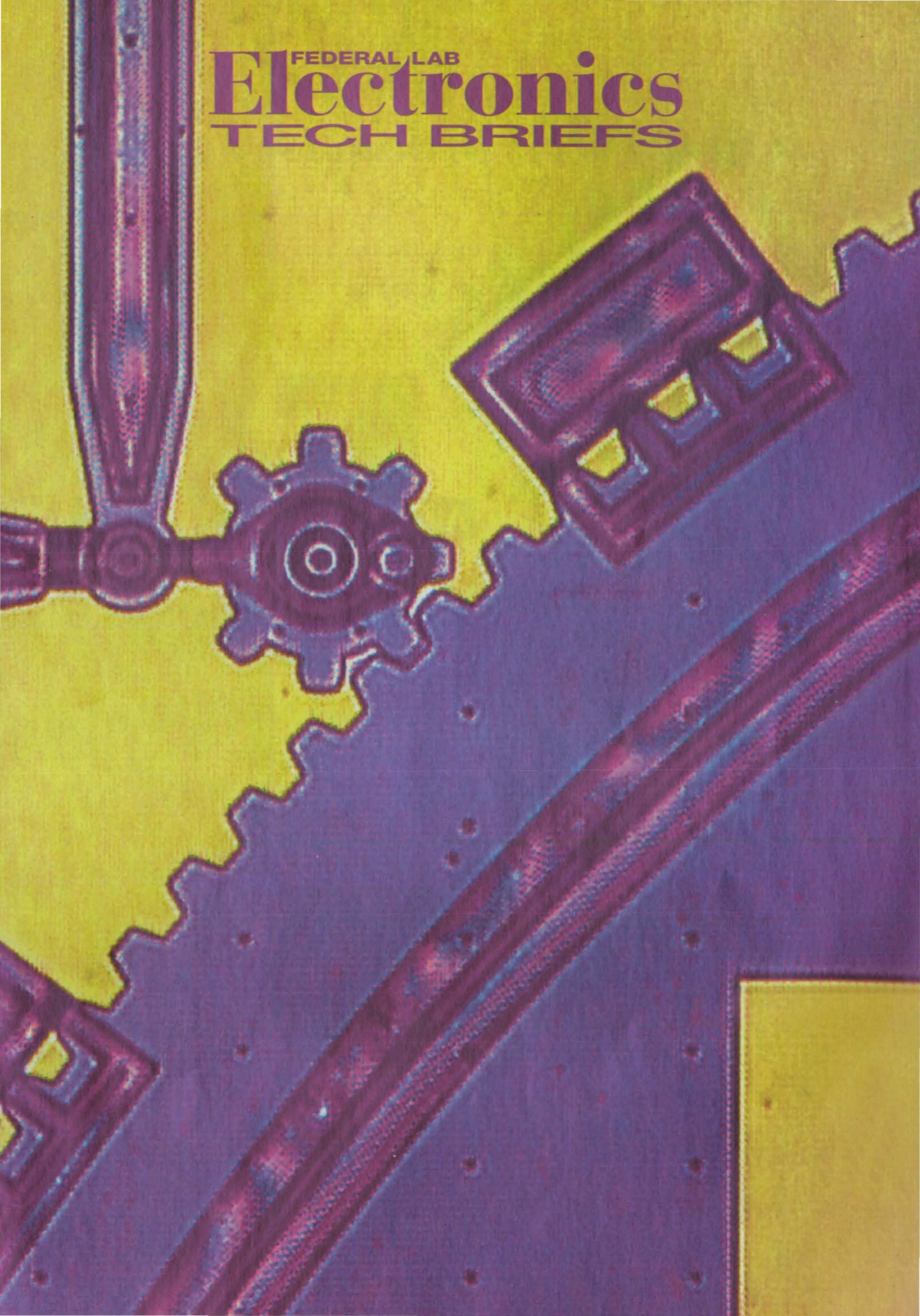
$SbCl_5$ Is the Source of Antimony Dopant in silicon deposited from chemical vapors. $SbCl_5$ is a liquid at room temperature and can be used in a typical chemical-vapor-deposition reactor like those in common use.

Previously, in chemical vapor deposition in which organometallic compounds were used as sources of dopants, it was found that the carbon in those compounds gave rise to carbon contamination in the deposited materials. The absence of carbon in the compounds used in the present method eliminates that particular source of contamination.

Epitaxial silicon doped with antimony can be deposited to arbitrary thickness by the present method. Demonstration deposits have been made in thicknesses up to 25 μm, with residual impurity concentrations as low as 10^{12} atoms/cm^3 and with antimony-dopant densities from less than 10^{17} to more than 4×10^{18} atoms/cm^3.

This work was done by James E. Huffman and Bradley L. Halleck of Rockwell International Corp., Science Center for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 72*** *on the TSP Request Card. NPO-19425*

FEDERAL LAB Electronics TECH BRIEFS



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Federal Lab Electronic Tech Briefs Supplement to *NASA Tech Briefs* March 1996 Issue Published by Associated Business Publications in cooperation with the Federal Laboratory Consortium for Technology Transfer

ELECTRONIC TECH BRIEFS

DEPARTMENTS

On the cover:
A team of scientists and engineers at Sandia National Laboratories' Albuquerque facility are pioneering the development of micromachinery. In the photo, a microgear smaller than a human hair drives a gear 30 times its size at 4800 rpm. Sandia researchers say theirs was the first silicon micromotor to drive external gearing and to be built entirely by microelectronic fabrication. The rectangular brackets on the large gear prevent it from warping. It functions as an optical shutter when light passes through the rectangular opening (partially shown, bottom right) in certain gear positions. *Photo courtesy Sandia National Laboratories.*

NEWS BRIEFS

News of the Industry and Federal Laboratories

University of Michigan scientists have conceived an electron accelerator capable of producing the shortest electron pulses on record and accelerating them to very high energies. According to Donald Umstadter, associate research scientist in the U-M's Center for Ultrafast Optical Science, coupling advanced laser technology with tabletop particle accelerators may make the latter as common in scientific research laboratories as the electron microscope. The development of chirped pulse amplification (CPA) in 1987 made it possible to generate very short laser pulses with peak powers as high as 100 trillion watts. Gerard Mourou, director of the U-M center, explains that focusing such power on a spot many times smaller than the period at the end of a sentence produces beams of enormous intensity. "The electric field surrounding this focal spot is strong enough to trap subatomic particles like electrons and accelerate them to high energies within just a few centimeters, instead of many kilometers as in conventional particle accelerators," Mourou says. Among a series of U-M experiments last year, scientists demonstrated the first collimated electron beam accelerated by a laser alone, running laser pulses through a gas jet to produce a plasma wave capable of accelerating electrons to energies of 1 billion eV in a distance of one centimeter. The National Science Foundation supports research at the center.

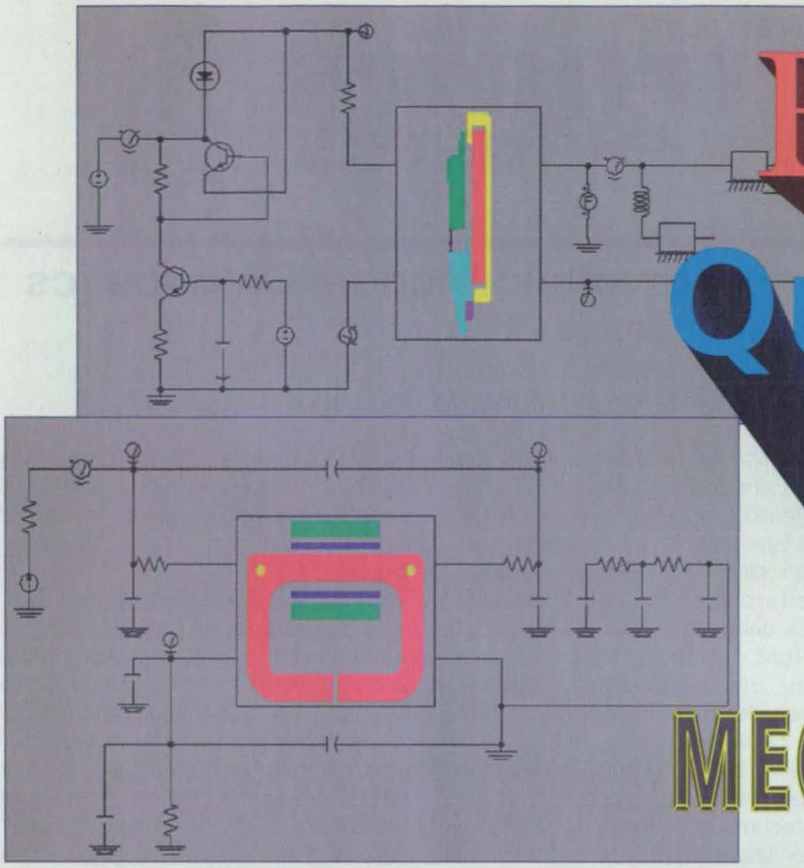
Researchers at the National Institute of Standards and Technology (NIST) have developed a new method for calibrating performance measurements on monolithic microwave integrated circuits (MMICs). These microelectronic chips are finding a place in wireless communications and "smart" transportation systems, but they challenge conventional means of charting performance. Dylan Williams and Roger Marks of NIST's Electromagnetic Fields Division (Boulder, CO) have come up with a way of deriving accurate results at high frequencies on a wide variety of MMICs fabricated with both coplanar waveguide and microstrip transmission lines. For more information contact Robert Judish, Div. 813.06, NIST, Boulder, CO 80303-3328; (303) 497-3380; E-mail: judish@boulder.nist.gov.

The Naval Research Laboratory has awarded Spire Corp. (Bedford, MA) a contract to further development of two innovative electronic circuits: monolithic complementary heterojunction bipolar transistor (CHBT) push-pull power amplifiers and operational amplifiers. Phased-array radar and mobile phone communications can utilize high-efficiency microwave and millimeter-wave power amplifiers, and operational amplifiers find broad application in analog electronics requiring high speed A/D and D/A converters. Spire will use selective metallorganic chemical vapor deposition to integrate both NPN and PNP heterojunction bipolar transistors on one wafer in a planar topography. The company plans to involve end users in the work during the circuit design phase.

The Materials Research Society gave Federico Capasso of Bell Laboratories (Murray Hill, NJ) its medal, honoring outstanding innovations and discoveries that promise to advance materials science significantly, for his work in engineering semiconductor research and design. A 19-year veteran of Bell Laboratories, Capasso pioneered a technique known as bandgap engineering, which can create materials with electrical and optical properties that do not exist in nature. Mark Melliar-Smith, chief technical officer at AT&T Microelectronics, called Capasso's discovery of artificially structured materials "as significant to the semiconductor industry as is genetic engineering to biology." By controlling layer thickness in materials grown with molecular beam epitaxy, Capasso and his Bell Labs research team have opened the way for a new family of semiconductor devices, including detectors, lasers, and transistors.

Scientists at the Department of Energy's Oak Ridge National Laboratory (ORNL) and the University of Tennessee have combined forces in the Joint Institute for Molecular-Based Engineering and Science (JIMBES). The institute will exploit the neutron and x-ray scattering methods and molecular-level computational techniques spawned at the two sites, applying physical and biological sciences to the development of new products and processes. The Small Angle Neutron Scattering facility at ORNL enables researchers to perform molecule-level experiments that complement their calculations.

BIOSYM/Molecular Simulations, a San Diego-based developer of molecular simulation systems, has given the University of Chicago $10 million in computer software under a cooperative research and development agreement. University scientists and employees of the company will explore ways in which these computer tools can enhance research and development, technology infrastructure, curriculum design, networking, training, and new forms of imaging such as virtual reality. The University will assume a leading role in molecular research next year when the Advanced Photon Source, a $480-million synchrotron, opens at Argonne National Laboratory, which is operated by the University for the Department of Energy.



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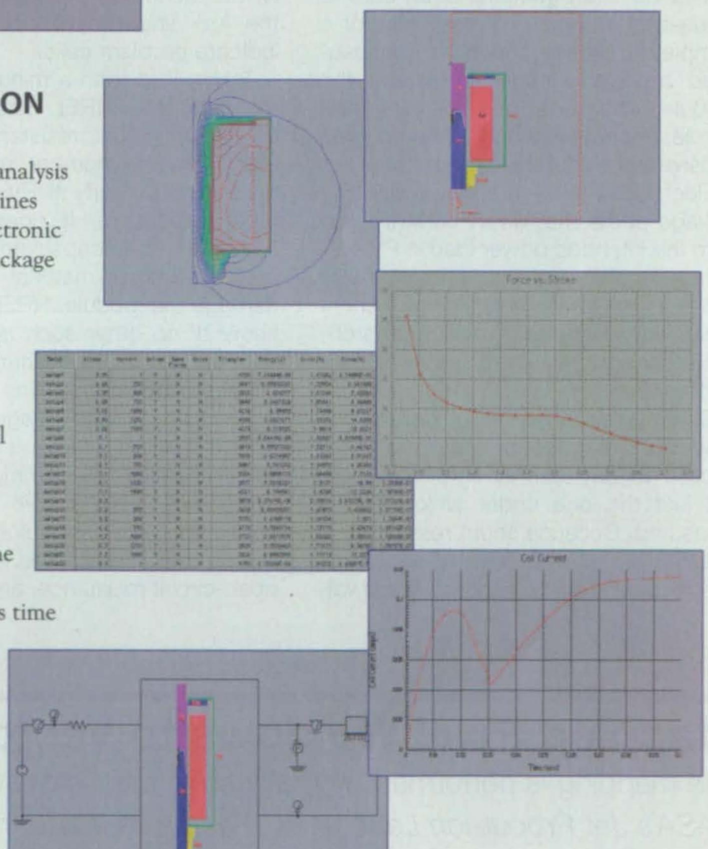

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For More Information Write In No. 463

Simple Analytic Tool for Photovoltaic Module Diagnostics

A nondestructive technique measures shunt resistance of individual cells to quickly identify electrical performance problems.

National Renewable Energy Laboratory (NREL), Golden, Colorado

Shunt resistance is one of the most basic and informative parameters of photovoltaic (PV) performance. Low shunt resistance of individual cells should be one of the first red flags in identifying electrical performance problems with PV modules. Until now, however, once a module was encapsulated, it was no longer practical to measure those resistances.

Researchers at the NREL recently developed a method that allows easy and accurate measurement of the shunt resistance, from fractions of an ohm to thousands of ohms, of each cell of a completed series-connected encapsulated module, without damaging the module. The technique is quick and simple, and requires only standard inexpensive electronic equipment.

Electrical shunts are low-resistance leakage paths that divert current away from the intended power load in PV systems. For PV modules with otherwise effective materials and design, shunt losses are a principal symptom of problems that can cause cell failure or poor performance.

Shunt resistance is a particularly powerful diagnostic parameter. It applies to any normal light condition, not just the one under which it was measured. Because shunt resistance is quantitative, you can set threshold values for quality control and compare values from different cells or modules. You can also check the values again after stress testing or regular use, or if the module later fails. Shunt-resistance values can also be used in computer models to predict the performance of modules under the varying intensity of actual light conditions for a particular location. Shunt-resistance measurement can detect problems within individual cells that are not readily detectable by traditional full-module current-voltage (I-V) tests. And the NREL technique is most accurate for the low shunt-resistance values that indicate problem cells.

Taking less than a minute per cell to measure, the NREL technique gives cell-by-cell shunt resistance for modules with any number of series-connected cells (nearly all PV modules currently produced). It does so without having to de-encapsulate--remove the protective cover material--or otherwise damage the module. NREL researchers know of no other such nondestructive test for individual-cell shunt resistance.

This technique requires an AC signal generator, a DC voltage supply, an operational amplifier, and a phase-sensitive amplifier, all common laboratory equipment. This simple technique is based on sequentially blocking the light to each cell in a module, measuring the open-circuit resistance, and subtracting the open-circuit resistance of the fully exposed module. If that difference is small, the cell has low shunt resistance that will significantly impair its performance.

Individual-cell shunt-resistance testing is valuable for all phases of the PV product's life. Measuring shunt resistance can verify the adequacy and optimization of cell fabrication steps; it can be used for module performance characterization and qualification testing; during manufacture, it can be an excellent quality-control and quality-assurance tool; and it is very helpful for failure analysis.

The technique is a simple diagnostic tool that gauges one of the most informative parameters of PV cell and module performance. It allows quick and easy testing of series-connected cells for any size module without damaging it. It is particularly valuable for assessing thin-film PV modules, many of which, even before encapsulation, do not allow access to individual cells without causing damage.

This work was done by Tom Basso and Tom McMahon of the **National Renewable Energy Laboratory**. *Inquiries concerning patent status and availability of rights and licenses should be directed to the NREL Technology Transfer Office at (303) 275-3008.*

Mapping Pixel Windows to Vectors for Parallel Processing

The mapping is performed by matrices of transistor switches.

NASA's Jet Propulsion Laboratory, Pasadena, California

Arrays of transistor switches have been devised for use in forming simultaneous connections from (1) a square subarray (window) of $n \times n$ pixels within an electronic imaging device that contains an $np \times np$ array of pixels to (2) a linear array of n^2 input terminals of an electronic neural network or other parallel-processing circuit. In mathematical terms, the transistor switches implement binary switching matrices that map the pixel window to an n^2-dimensional vector (see figure); that is, the brightness-level output signal of each pixel constitutes one component of the vector, while the vector constitutes the collection of inputs to the parallel-processing circuit.

This mapping method helps to realize the potential for rapidity in parallel processing for such applications as enhancement of images and recognition of patterns. In providing simultaneous connections, this method overcomes the timing bottleneck of older multiplexing, serial-switching, and sample-and-hold methods.

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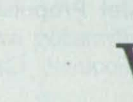

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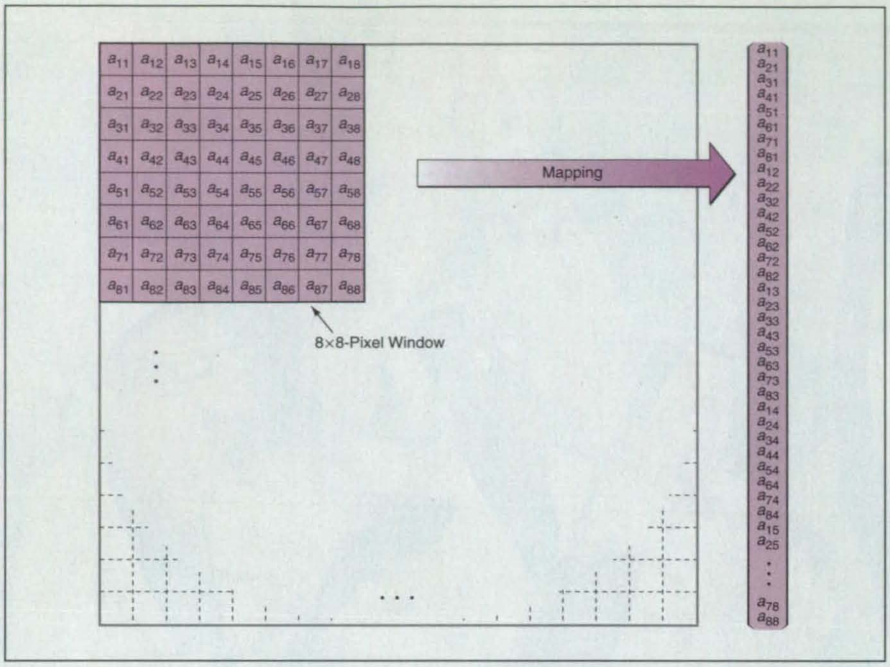


All The Pixels in the Selected 8 × 8 Window are mapped simultaneously to positions along a 64-element linear array or, equivalently, to components of a 64-dimensional vector.

In addition, these older methods lack flexibility of connection patterns, whereas in the present method, the connection patterns can be varied at will by changing the matrix elements. Changing connection patterns can result in rearrangement of the sequence of components of the vector. Changing connection patterns can be used for a variety of purposes; for example, rotating or translating the window image fed to the parallel processor.

The mapping is performed in two stages. In the first stage, the mapping is from the pixels of the selected window to an intermediate windowlike $n \times n$ array of nodes. For this purpose, there must be a total of p^2 switches fanning in to each node from the corresponding pixels of the p^2 windows, and for each node, one of these switches is turned on to receive the signal from the corresponding pixel of the selected window. Thus, this mapping requires n^2p^2 switches and is represented by an $np \times np$ matrix, which is denoted as T.

It is possible to select an $n \times n$-pixel window that straddles one or more boundaries between adjacent $n \times n$ subdivisions of the overall $np \times np$ array of pixels. In such a case, the T-mapping yields vector components in the incorrect sequence. The second-stage mapping corrects the sequence. This mapping is represented by an $n^2 \times n^2$ matrix, M, and requires n^4 switches — one switch from each of the n^2 nodes to each of the n^2 input terminals of the parallel processor. M is also used to rearrange the components of the vector as needed for the desired transformation (e.g., rotation or translation) of the window image.

The "brute-force" method for effecting the same mapping with a flexible connection pattern requires $O(n^4p^4)$ switching transistors [where $O(x)$ denotes a number proportional to a number of the order of x]. For reasonable values of n and p (e.g., n, $p \geq 8$), the circuitry needed to implement so many switches can be very complex and large, and its parasitic capacitance can be excessive. The present method can be implemented with simpler, smaller, and less expensive circuitry because it requires a smaller number of switching transistors; namely, $O(n^2p^2+n^4)$.

This work was done by Tuan A. Duong of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 99*** *on the TSP Request Card.* *NPO-19431*

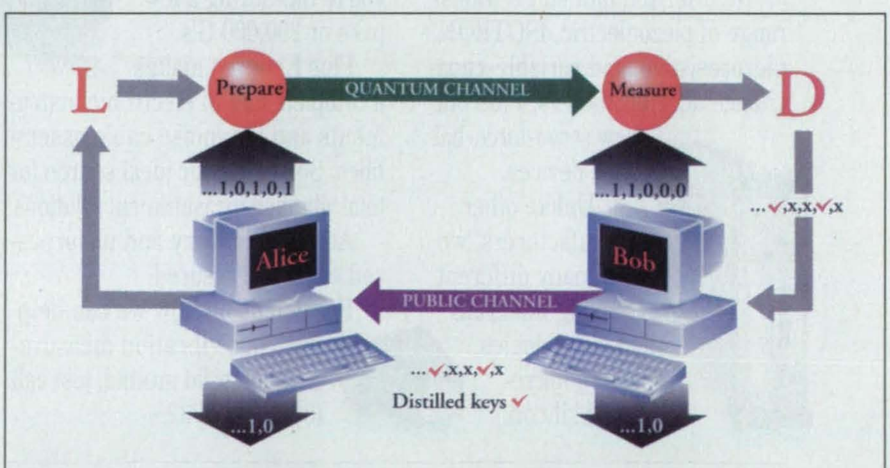
Secure Communications Using Quantum Cryptography

Security over "open" fiber networks can be obtained through shared cryptographic key material with single-photon transmissions.

Los Alamos National Laboratory, Los Alamos, New Mexico

Cryptography, the science of secret communications, is becoming increasingly important with the growth of computer networks and electronic transmissions. When personal, financial, military, or national security information is transferred from place to place, it becomes vulnerable to eavesdropping tactics that have catastrophic potential. The goal of encrypting information can be accomplished if the sender and recipient both possess a secret random bit sequence (binary numbers), known as "key" material, which is used for encryption by the sender and decryption by the recipient.

Key material is therefore a valuable resource even though it conveys no information itself. But the initial step of "key distribution," whereby the two parties acquire the key material, must be



The **Single-Photon Laser Source** (L) initiates the quantum key-generation process by sending a signal on the quantum channel to a detector that sorts out the correspondences between the parties' 0s and 1s, setting up a common subset as shown by the "distilled keys" (checks).

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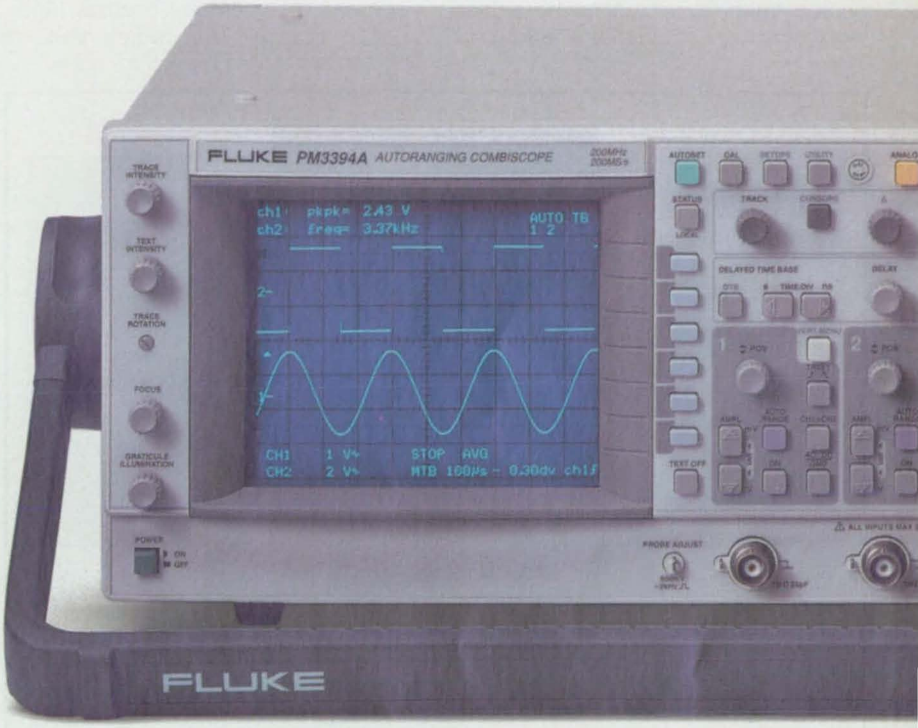

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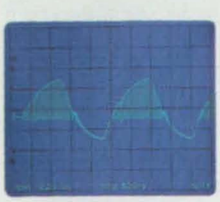

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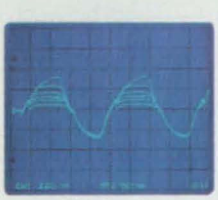

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accomplished with a high level of confidence that a third party cannot acquire even partial information about the bit sequence.

With conventional communications, which can be subject to passive monitoring by an eavesdropper, it is impossible to generate a certifiably secret key, and so cumbersome physical security measures for key generation, distribution, storage, and destruction after use are required. Secure key distribution becomes possible, however, if the two parties can communicate with single-photon transmission using the emerging technology of quantum cryptography, or more accurately, quantum key distribution (QKD).

The security of QKD is based on fundamental principles of quantum physics. A unique technology facilitates the unbreakable encryption of communications between secure "islands" over "open" optical fiber networks by allowing key generation to take place at the time it is required.

Two parties (Alice and Bob in the figure) start a quantum key-generation procedure by producing their own independent sets of random bits. They possess a quantum channel and a public channel over which they can compare their numbers to distill a common subset.

Alice proceeds by preparing a single photon with her laser source (L) for each bit in her set of numbers in one of two possible ways, depending on whether her number is a 0 or a 1. Each photon is then sent over the quantum channel. Bob, who also proceeds through his numbers bit by bit in synchronization with Alice, performs one of two possible measurements on each photon, depending on whether his number is a 0 or a 1.

A photon will never trigger Bob's detector (D) if his number is different from Alice's, but it will do so with a 50% quantum-mechanical probability if their numbers are the same. Bob labels a number from his set as a "hit" if he detects a photon and then passes this information (but not the number itself) to Alice over the public channel. Alice then labels her numbers that were hits on Bob's end, and a shared secret key emerges as the common set of hit bits.

QKD only identifies 50% of the bits shared by Alice and Bob, but this inefficiency is the price of immunity to eavesdropping: physical laws ensure that Alice's two preparations (0 or 1) cannot be distinguished with 100% probability by either Bob or the eavesdropper. So eavesdroppers who attempt to tap into the quantum channel are unable to intercept the key data because they cannot attach 0 or 1 labels to the photons that Alice sends. Furthermore, Alice and Bob can detect eavesdropping because the methods used to "siphon" photons off the quantum channel irreversibly alter their states.

Los Alamos is developing a fiber optical implementation of QKD. For long propagation distances (greater than 1 km), the production and detection of single photons at a wavelength of 1.3 micrometers is required. Because there are no commercial single-photon detectors available at this wavelength, the first task was to develop this capability. The team has already demonstrated key distribution in a laboratory environment with an all-fiber QKD prototype. It is expected that a quantum-cryptographic link can be established over optical fibers between two areas separated by a distance of 7.5 km.

This work was done by the Physics Division of **Los Alamos National Laboratory**. *For more information, contact Dr. Richard J. Hughes, Neutron Science and Technology Group (P-23), MS D406, LANL, Los Alamos, NM 87545; (505) 667-3876; E-mail: hughes@lanl.gov.*

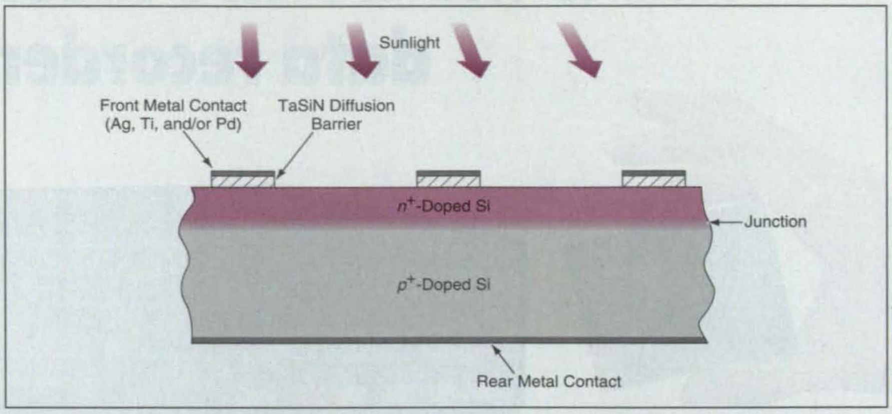
Diffusion-Barrier Contacts for Solar Cells

The barriers enhance performance at low temperatures and low light intensities.

NASA's Jet Propulsion Laboratory, Pasadena, California

Diffusion-barrier contacts can be incorporated into silicon-based solar photovoltaic cells to reduce degradation of performance at low temperatures and low light intensities. Heretofore, the low-temperature, low-light-intensity performances of such cells have been degraded by interactions that occur between metal contacts and silicon during fabrication.

The present diffusion-barrier contacts are thin, electrically conductive strips of TaSiN, which are deposited on the front surface of each affected cell. The strips of the front-surface metal contact grid are then deposited on the diffusion-barrier contacts (see figure). The diffusion-barrier contacts prevent diffusion of metal into the silicon at the high processing temperature.



Electrically Conductive Diffusion Barriers of TaSiN prevent diffusion of metal from the overlying metal contacts into the underlying silicon during processing at high temperature, thereby improving performance during subsequent use in low-intensity light at low temperature.

This work was done by Paul M. Stella, Frederick S. Pool, and Marc Nicolet of Caltech and Peter A. Iles of Applied Solar Energy Corp. for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 8*** *on the TSP Request Card. NPO-19513*

Neutron Diffraction Determines Stresses in Materials

The Intense Pulsed Neutron Source can assess quality and life expectancy.

Argonne National Laboratory, Argonne, Illinois

With a unique combination of analysis and research instruments developed at Argonne National Laboratory, scientists can use the lab's Intense Pulsed Neutron Source (IPNS) to interrogate materials that make up ceramic engine parts, nuclear reactor components, and advanced jet engines and make predictions about their quality and life expectancy.

Large residual stresses can develop in composites during fabrication, and determination of these stresses is crucial for predicting composite performance. By learning how cooling, heating, and processing affect residual stress, stronger and tougher composites can be developed. The only effective, nondestructive way to measure internal residual stress in composites is with neutron diffraction. Neutrons penetrate materials and permit bulk measurement of strain, whereas x-rays measure only surface stresses.

IPNS is a pulsed source with six detector banks that can provide diffraction data in various spatial directions simultaneously. A number of companies and laboratories are using this data to understand the processing of composites and to validate computer models that predict mechanical properties. The result could be improved processes that make better composites.

Argonne tests critical materials for industry, such as advanced ceramic and metal-matrix composites, high-temperature superconducting materials, and nuclear reactor component mockups. The information supplied to industry is used to modify product design. This work is conducted by a research team of physicists, mechanical engineers, ceramists, and instrument scientists from three Argonne divisions using information from IPNS.

With neutron penetrations of up to many millimeters, neutron diffraction offers the unique capability of providing bulk measurements. If both macrostresses, from welding or surface finish, and microstresses (those on the scale of the microstructure) are present, the macrostresses are averaged out within the sampling volume, thus making the microstresses directly accessible. This is a significant advantage over x-ray diffraction, which measures only near-surface stresses that may include macrostresses.

The application of neutron diffraction to the determination of stress is a relatively new technique that has been validated at Argonne mainly for composites, but also for large components such as turbine rotors, large bearings, and large welds. At present, through the user program, IPNS is available to any industry interested in determining residual as well as applied stress. The facility is also accessible to university users. Components can be studied at IPNS while undergoing changes in temperature, pressure, and atmosphere during measurement. Strain can be measured to a sensitivity of one part in 10,000.

This work was done by Dick Hitterman, Dave Kupperman, Saurin Majumdar, Jim Richardson, and J.P. Singh of **Argonne National Laboratory**. *These researchers hold a patent on a neutron stress monitor for composites.*

IPNS is a national user facility. Beam time can be obtained on one of the instruments by having a proposal approved by the oversight committee or by purchasing time from the IPNS division. If an experiment is assigned time on an instrument, Argonne staff will be available to assist a company's staff in completing the work.

Companies interested in working with this facility are encouraged to mail or FAX a letter to the Industrial Technology Development Center, ITD-900, 9700 S. Cass Ave., Argonne, IL 60439; FAX (708) 252-5230.

CCD Detects Two Images in Quick Succession

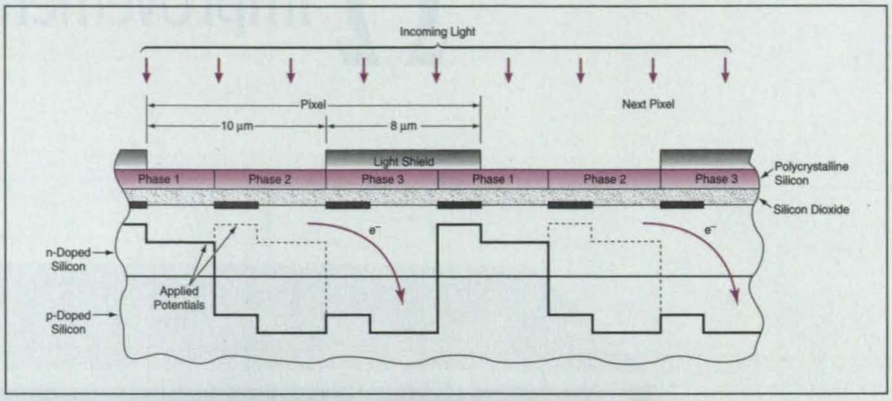
Readout is performed slowly to minimize noise.

NASA's Jet Propulsion Laboratory, Pasadena, California

A prototype special-purpose charge-coupled device (CCD) is designed to detect two 1,024 × 1,024-pixel images in rapid succession (typically, separated by < 100 ns). When fully developed, this CCD would be operated in synchronism with a pulsed laser, stroboscope, or other pulsed source of light to form pairs of images of rapidly moving objects.

The basic design of this CCD is similar to that of a standard 3-phase, buried-channel CCD, except that within each pixel, an implant is added to each phase, and a light shield is added to phase 3 (see figure). A typical sequence of operations involves two flashes of light separated by the desired interval of the order of 100 ns. During the first flash, the first image is formed in phases 1 and 2 of the pixels (but not in phase 3 because of the light shields). During the interval of darkness between the first and second flashes, this first image is transferred to phase 3, where it is stored for subsequent readout.

The second image is formed in phases 1 and 2 during the second flash of light and is then stored in phases 1 and 2 for subsequent readout. Thereafter, the first and second images are read out from the CCD by clocking phases 1, 2, and 3 of the pixels in the appropriate sequence. The readout time is chosen to be much longer than the interval between flashes (readout is performed in a slow scan) to minimize readout noise. The design level of readout noise is about 3 electrons, root mean square, per pixel.



This **Modified Three-Phase CCD** is operated in synchronism with two pulses of light to detect two images. The first image is formed in phases 1 and 2, then quickly transferred to phase 3. The second image is formed and stored in phases 1 and 2. Then the two images are read out in a slow scan.

This work was done by James R. Janesick and Andy Collins of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 93*** *on the TSP Request Card.* *NPO-19291*

Electroabsorption in Doped Asymmetric Double Quantum Wells

The modulator uses real-space electron transfer to provide efficient absorption modulation.

Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

Electro-optic nonlinearities in semiconductor heterostructures have become an important means of transducing electronic data onto optical signals for communications systems. The most common nonlinearity employed to produce electro-absorption and electro-refraction in semiconductor quantum wells is the quantum confined Stark effect (QCSE). For materials systems such as (Ga,In)As/(AL,In)As quantum wells latticed-matched to InP, which are compatible with the optical fiber transmission windows of 1.3 and 1.5 µm, the QCSE is small, because of the relatively low electron and heavy-hole effective masses and the restriction on suitable well widths, i.e., 40 and 85 Å respectively. Although recent results utilizing the (Ga,Al,In)As/(Al,In)As on InP system have demonstrated improved material quality and device performance at these wavelengths, improvements in the electro-optic characteristics of these materials is still required. One novel electroabsorption mechanism is based on selective doping of (Ga,In)As/(Al,In)As asymmetric double quantum wells (ADQWs).

The team designed an ADQW structure in which an excess conduction-band electron density is intentionally formed by selectively doping the wide-well (WW) n-type as shown in Figure 1(a). The presence of excess electrons bleaches the absorption near the band-edge of the WW. The lowest energy transition in the WW is thus given by:

$$\hbar\omega = E_{\mu=0} + \mu_e(F) + E_{\parallel}^{v}$$

where $E_{\mu=0}$ is the lowest-energy WW transition in the absence of excess electrons, $\mu_e(F)$ is the field-dependent electron quasi-chemical potential with respect to the lowest allowed energy in the WW, and $E^{v}_{\parallel}$ is the in-plane hole energy required for momentum conservation. Hence, the equation indicates that the WW absorp-

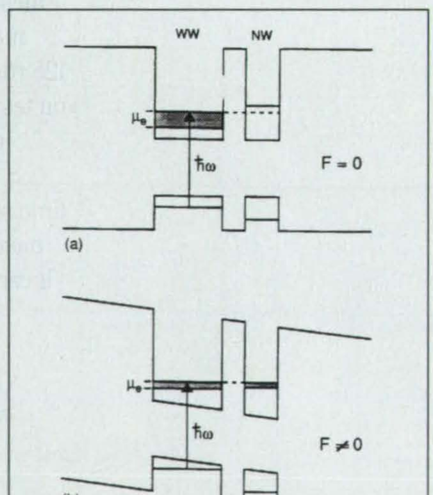


Figure 1. **Conduction and Valence Band** structures of the doped ADQW modulator in the (a) unbiased F=0 and (b) unbiased F≠0 states. The shaded regions represent states occupied by excess electrons.

tion edge will be blue-shifted with respect to the absorption edge in the absence of excess electrons, i.e., $\mu_{e=0}$. An electric field applied perpendicular to the plane of the quantum wells will reduce the energy separation between the lowest electron levels in the wide and narrow wells as shown in Fig. 1(b). As a result, the excess electrons localized in the WW can tunnel to the narrow well (NW), a process known as real-space electron transfer. The transfer of the electrons reduces μ_e, resulting in the recovery of the absorption near the WW band-edge and causing an apparent red-shift of the WW absorption edge.

The doped ADQW modulator structure was grown by molecular beam epitaxy on n-type (100) InP substrates. The electrical bias was applied via an *n-i-n* diode consisting of a 0.35-μm layer of n-type $Ga_{0.3}Al_{0.18}In_{0.52}As$(Si,2X10^{18} cm^{-3}) followed by a 0.865-μm intrinsic region and capped with a 0.2-μm layer of n-type $Ga_{0.3}Al_{0.18}In_{0.52}As$(Si,2X10^{18} cm^{-3}). The intrinsic region consisted of 30 periods of 100-angstrom $Al_{0.48}In_{0.52}As$ barrier/70-angstrom $Ga_{0.47}In_{0.53}As$ wide-well doped n-type over the central 40-angstrom (Si,1X10^{12} cm^{-2})/35-angstrom $Al_{0.48}In_{0.52}As$ tunnel barrier/50-angstrom $Ga_{0.47}In_{0.53}As$ narrow-well, all between two layers of 500-angstrom undoped $Al_{0.48}In_{0.52}As$. The diodes were processed into mesa diodes 150 μm in diameter with ring-top contacts to allow optical transmission experiments. The modulator sample was mounted in a closed-cycle helium cryostat and held at a temperature of 50 K.

The measured absorptance spectra at bias fields of 0 and 74 kV/cm, corresponding to applied voltages of 0 and 6.4 respectively, are shown in Fig. 2. The

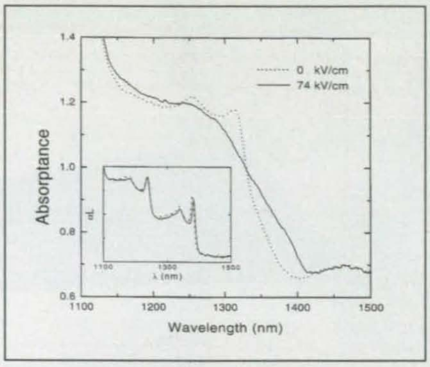


Figure 2. **Measured Absorptance Spectra** of the doped modulator for applied fields of 0 and 74 kV/cm. The inset shows the measured absorption spectra of the undoped structure at the same applied fields.

peaks in the zero-field spectrum are the light- and heavy-hole excitonic absorption features associated with the lowest-energy transition in the NW. The excitonic features associated with the WW, however, are completely bleached by the presence of the excess electron density. In fact, due to band-filling in the first WW electron subband, the WW absorption is bleached to wavelengths approaching the NW band-edge. With the applied field present, the absorption associated with the WW recovers while the absorption associated with the NW becomes bleached. It should be stressed that the observed changes are not due to the QCSE. In undoped (Ga,In)As/(Al,In)As-coupled quantum-well systems consisting of similar well widths, excitonic absorption features persist to much higher applied fields than those considered in this work. Hence, the observed absorption changes can only arise from the real-space transfer of electrons from the WW to the NW.

The characteristics of the doped modulator were compared to the electroabsorption characteristics of an undoped ADQW structure. The red-shift of the band-edge for the undoped sample is quadratic with increasing field, as expected from the QCSE (see inset of Fig. 2). However, the red-shift of the band-edge exhibited by the doped sample is much larger with increasing field and has an almost linear field dependence. In fact, for an applied field of approximately 50 kV/cm (corresponding to an applied voltage of only 4.3 V) the red-shift of the doped sample is more than six times larger than the red-shift of the undoped sample.

In this novel electroabsorption mechanism based on selective doping in ADQW structures, the modulator uses real-space electron transfer to provide efficient absorption modulation. The doped modulator exhibits a significantly larger red-shift with applied field than an undoped structure that uses the QCSE. Efforts are currently under way to optimize the coupled quantum-well design and diode structure for room-temperature operation.

This work was done by M.F. Krol of **Rome Laboratory's Photonics Center,** *R.P. Leavitt and J.T. Pham of the US. Army Research Laboratory, and B.P. McGinnis and N. Peyghambarian of the Optical Sciences Center, University of Arizona, Tucson, AZ. No further information is available.*

Inquiries concerning the rights for the commercial use of this technology should be addressed to Rome Laboratory Office of the JA, Griffiss AFB, New York 13441.

Temperature-Compensated Sapphire Microwave Resonator

Ultrastable operation can be achieved at relatively low cost.

NASA's Jet Propulsion Laboratory, Pasadena, California

A sapphire-dielectric-ring microwave resonator that operates in a "whispering-gallery" electromagnetic mode features a differential-thermal-expansion design that provides temperature compensation for ultrahigh frequency stability. Heretofore, sapphire-ring resonators have been temperature-compensated by addition of paramagnetic impurities, but this approach has proven effective only at temperatures ≤ 6 K. The present resonator is a prototype of a type of sapphire resonator designed to minimize frequency fluctuations caused by temperature fluctuations at a nominal temperature equal to or even somewhat greater

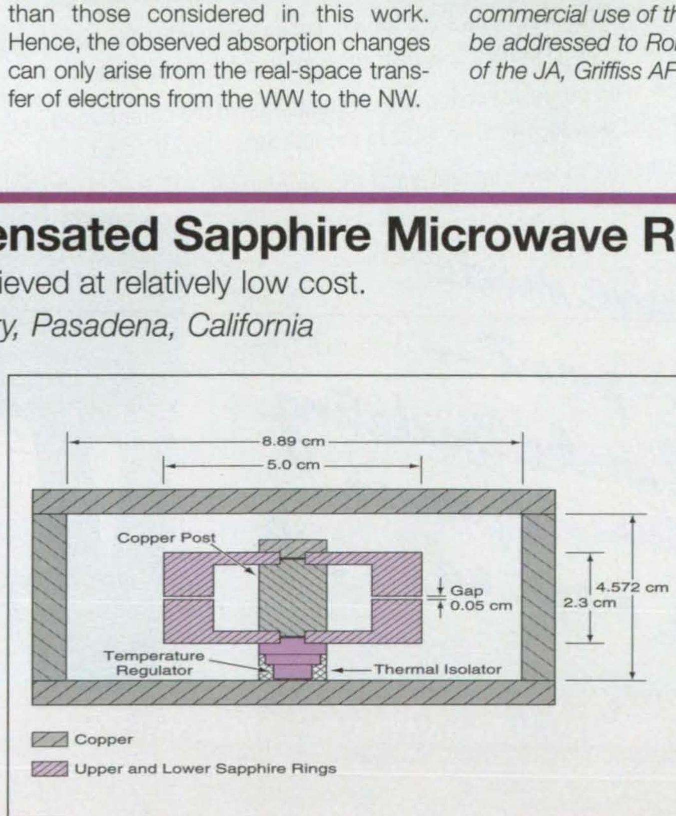


Figure 1. The **Thermal Expansion of the Copper Post** causes the frequencies of the electromagnetic modes of the resonator to increase with temperature, while thermal effects in the sapphire cause the frequencies to decrease with temperature. These opposing effects can be utilized for temperature compensation.

than the temperature of liquid nitrogen (77 K). The ancillary equipment needed for operation in this higher temperature range is smaller and less expensive, and liquid nitrogen can be used as the coolant.

This resonator includes an upper and a lower sapphire ring separated by a small gap and spaced apart by a central copper post that is almost as tall as the rings are. The use of the small gap preserves the high Q (quality factor; a measure of the sharpness of resonance, defined as $2\pi \times$ the energy stored in the electromagnetic field in the resonator $\div$ the energy dissipated per cycle of oscillation) of the whispering-gallery modes of interest while giving a steep variation of frequency with the size of the gap. The tall copper post gives a relatively large motion due to thermal expansion. The central position of the copper post minimizes its tendency to degrade Q because the electromagnetic energy of the modes of interest is concentrated near the radially outermost surfaces of the sapphire rings.

Compensation occurs as follows: As the temperature increases, the mode frequencies decrease because of concomitant thermal expansion of the sapphire and a concomitant increase in the relative permittivity of the sapphire. However, because the thermal expansion of the copper post exceeds that of the sapphire, the gap widens. The resulting increase in the volume of the gap (relative permittivity of vacuum = 1, as compared with relative permittivity of sapphire $\approx$10) tends to increase the frequencies of the modes. At some temperatures, these opposing effects can cancel each other; in other words, result in complete temperature compensation.

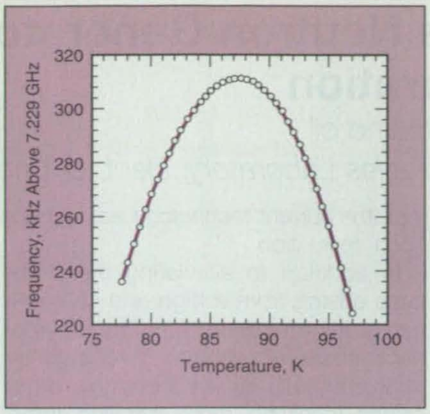


Figure 2. **Complete Temperature Compensation** of a 7.23-GHz mode of this resonator can be achieved by operating at 87.09 K, where the slope of the frequency-vs.-temperature curve goes to zero.

Figure 2 shows the measured temperature dependence of frequency for a mode with a nominal frequency of 7.23 GHz that is compensated at a temperature of 87.09 K. In this case, one could achieve a frequency stability characterized by a change in fractional frequency no greater than 10^{-14} during a typical observation interval 100 s long if one could maintain the temperature stable to within 43 µK. This requirement can be satisfied by use of conventional temperature-regulation equipment developed for frequency-standard oscillators. The projected fractional frequency instability of 10^{-14} of this resonator is less than that of a typical highest-quality quartz resonator, which is about 2×10^{-13}.

This work was done by G. John Dick and David G. Santiago of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 54*** *on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office–JPL [818-354-5179]. Refer to NPO-19414.

Using a Sealed Tube Neutron Generator for Fossil Fuel Exploration

A modified unit is designed to help find oil.

Nevada Test Site, Special Technologies Laboratory, Dept. of Energy, Las Vegas, Nevada

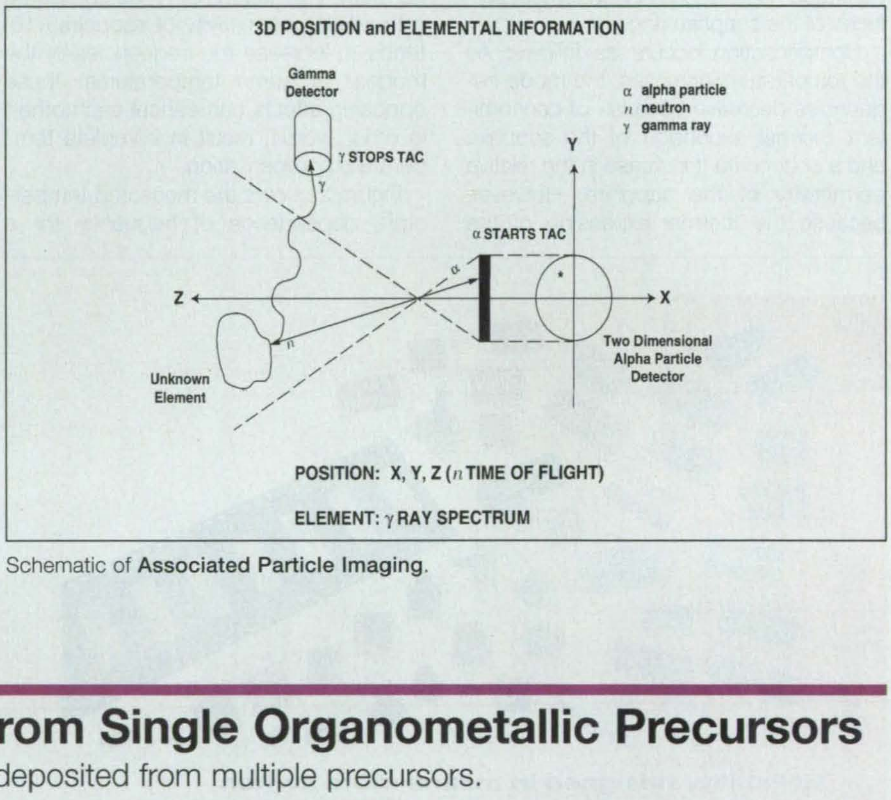
In the oil exploration industry, the standard method of performing downhole measurements involves inserting a small neutron generator into a mud-filled hole. The surrounding earth is then probed by a 14-MeV pulsed neutron source, and the ensuing gamma-ray spectra are observed as a function of time. Though the objective is to obtain data about the local geologic properties, the signals are superimposed on high background noise because of counts originating from the measurement apparatus itself. Obviously, it would be helpful to know the origin of each gamma ray and to be able to accept or reject the count accordingly. (At present, this background is estimated using the Monte Carlo analysis method, and subtracted from the data.)

DOE's Nevada Test Site (now Bechtel Nevada) scientists, working for EG&G Energy Measurements' Special Technologies Laboratory in California, modified a version of the sealed tube neutron generator to perform this function. Using such a tube with associated particle imaging methodology, one can determine the positional origin and the energy of each contributing gamma ray. Using the associated particle imaging technique may provide an advantage when performing downhole measurements to identify underground oil formations. Along with the background noise problem, the current technology lacks directional resolution.

In addition to alleviating the problems arising from a high and unidentified background, knowing the origin of each observed gamma ray would be instrumental in addressing other issues involving more detailed information about the surrounding geological strata. For instance, detection of an underground "pool" of oil sandwiched between two strata would suggest using a horizontally drilled section to facilitate more efficient pumping. The angle of stratified layers is another currently nondiscernable parameter that would optimize pumping efficiency.

Because drilling an oil well is still very expensive and risky, any technology that significantly increases the chances of success is particularly valuable. Scientists have made initial contacts with an industrial partner to test this technology in the field.

This work was done at the Dept. of Energy's **Nevada Test Site**. *For more information, contact Dr. Bruce Whitcomb, Principal Scientist, Office of Research and Technology Applications, Bechtel Nevada, PO Box 98521, M/S NLV006, Las Vegas, NV 89193-8521; (702) 295-3164.*



Schematic of **Associated Particle Imaging**.

CVD of Thin Films From Single Organometallic Precursors

These films are superior to films deposited from multiple precursors.

Lewis Research Center, Cleveland, Ohio

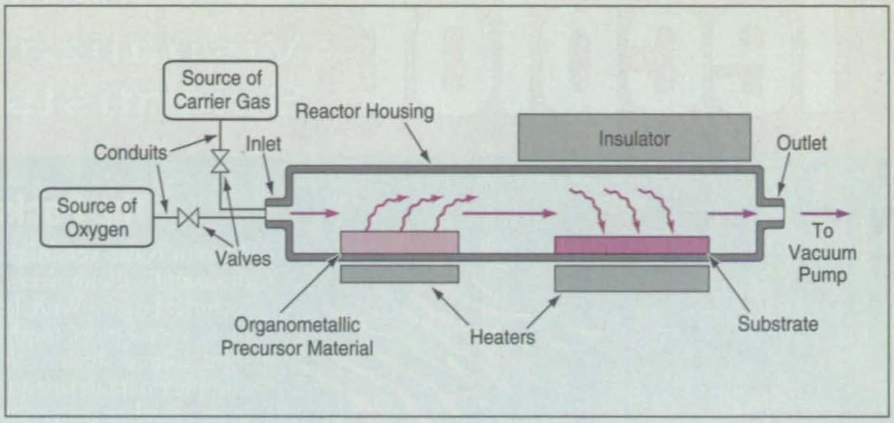
A method of forming thin inorganic films involves chemical vapor deposition (CVD) from single organometallic precursors. The method is especially suitable for depositing high-quality passivating or buffer layers of GaS on GaAs semiconductor substrates. The method is also applicable to formation of high-quality films for purposes other than buffering or passivation, and to different materials in which another element from the same group in the periodic table of elements is substituted for all or a portion of each element in the GaS/GaAs system.

Previous methods of forming passivating or buffer layers on GaAs involved multiple chemical precursors. These methods resulted, variously, in layers that contained impurities, were of uneven composition, were unstable, were toxic, and/or had to be deposited at temperatures so high that substrates became degraded. In contrast, the present method involves no toxic constituents, minimizes impurities, and yields films that have substantially uniform crystal structure and composition.

The apparatus used in this method (see figure) includes a flow-through reactor housing connected via valves to (1) a vacuum pump, (2) a source of carrier gas (typically, argon, hydrogen, or nitrogen), and (3) an optional source of oxygen or a gas that can be decomposed to release oxygen (e.g., N_2O). The precursor material is placed in a holder in the chamber upstream from the substrate.

A heater plate outside the chamber near the precursor heats the precursor, through the wall of the reactor housing, to a temperature high enough to vaporize a sufficient quantity of the precursor; typically, this temperature is between 100 and 250 °C. A flow of carrier gas entrains the precursor and carries it toward the substrate. Another heater plate outside the reactor housing heats the substrate to a temperature at which the precursor is pyrolized; typically, this temperature is between 250 and 550 °C.

Upon arrival in the vicinity of the substrate, the precursor molecules are pyrolized by heat radiated from the substrate. The nonvolatile product (e.g., GaS) of the decomposition of the precursor molecules is deposited on the substrate, forming the film. The heaters and the flow of gas are turned off to stop the deposition when the deposit attains the desired thickness (typically between 2,000 and 5,000 Å).



The **Organometallic Precursor Material** is vaporized, carried to the substrate, and pyrolized to form a deposit on the substrate.

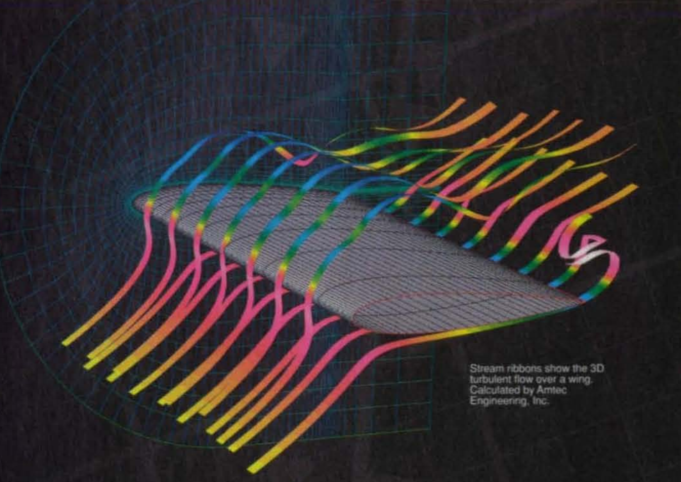
The precursor can be any of a number of organometallic compounds that contain butyl groups and the elements to be deposited. The composition and molecular structure of the deposited film depends on the precursor. For example, a precursor of $[(^{t}Bu)_2Ga(S^{t}Bu)]_2$ (where "^{t}Bu" denotes tertiary butyl) yields a film of amorphous GaAs.

An important class of examples is that of precursors that have cubane molecular structures or that acquire cubane molecular structures during vaporization or pyrolysis. These precursors yield films that have cubic or cubiclike crystalline structures, which are often desired because they can be lattice-matched with substrates of similar crystalline structure. For example, the cubane-structured precursor $[(^{t}Bu)GaS]_4$ forms a cubic-phase GaS passivating film that is lattice-matched to a GaAs substrate.

The optional source of oxygen is for use in forming an insulating oxide layer on the outer surface of the passivating film. When the film has been deposited to the desired thickness, the valve from the source of oxygen is opened; exposure to the flowing oxygen or oxygen-containing gas results in formation of the oxide surface layer.

This work was done by Aloysius F. Hepp of **Lewis Research Center**; *Andrew R. Barron of Harvard University; Michael B. Power and Andrew N. MacInnes of Gallia, Inc.; and Phillip P. Jenkins of Sverdrup Technology, Inc. For further information,* ***write in 58*** *on the TSP Request Card.*
LEW-15636

Tecplot® Interactive Data Visualization for Scientists & Engineers



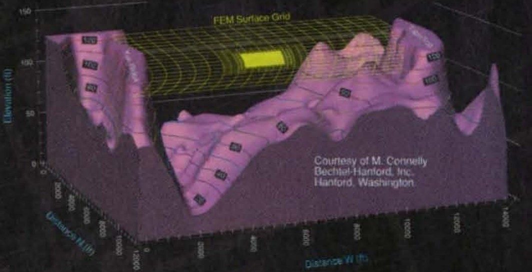
Stream ribbons show the 3D turbulent flow over a wing. Calculated by Amtec Engineering, Inc.

The Package Chosen by Thousands

Tecplot is the versatile and powerful, interactive software package that thousands of engineers and scientists have chosen for visualizing their technical data. With Tecplot you can easily create XY plots, contour plots, vector plots, mesh plots, carpet plots, 3D stream ribbons, isosurfaces, light-source-shaded surfaces, and many other plots. You can visualize complex data defined in one, two, or even three dimensions. You can even visualize data on its original non-rectangular grid (e.g., multi-block curvilinear, triangular, quadrilateral, 8-node bricks, and tetrahedral), preserving its original variation of grid resolution and retaining exact grid boundaries. Tecplot was elected "Best Data Visualization Software" of 1994 by the readers of Scientific Computing and Automation Magazine.

The Total Data Visualization Solution

Tecplot tightly integrates basic plotting and graphing with advanced scientific visualization techniques in one versatile package, making Tecplot the comprehensive solution to all your data visualization needs. Tecplot is easy to use, yet has the power, capacity, and flexibility to please even the most demanding research scientist. Tecplot's versatility and cross-platform support makes it ideal for a wide range of scientific and engineering applications. When considering a company-wide data visualization solution, think Tecplot.



Courtesy of M. Connelly Bechtel-Hanford, Inc. Hanford, Washington.

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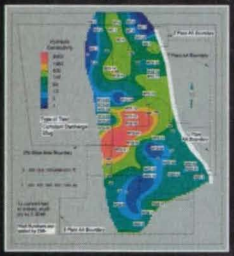
Are you spending too much time programming or getting frustrated trying to do scientific visualization with regular plotting programs? Use Tecplot to focus on your real work and begin producing results from the moment you read in your data. Tecplot enables you to interactively explore and analyze your data to gain new understanding and insights. With Tecplot, you can create beautiful, publication-quality plots in minutes.



Courtesy of M. Connelly, Bechtel-Hanford, Inc., Hanford, Washington.

Available for Unix, Linux, VMS Workstations and PC's.

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"Tecplot is the best engineering and scientific plotting package. I wish I could have used it when I was doing my Ph.D."
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"The best scientific plotting package around! Best technical support, too! I love it and have told everyone about it!"
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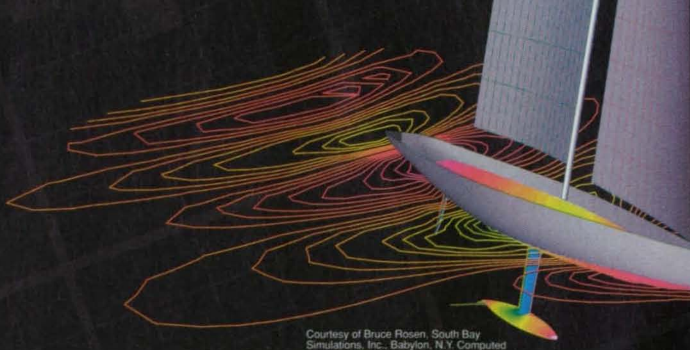
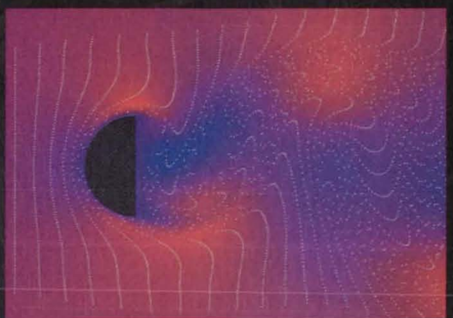


Courtesy of Bruce Rosen, South Bay Simulations, Inc., Babylon, N.Y. Computed results by SPLASH free-surface flow code.



Courtesy of R. D. Henderson and G. E. Karniadakis, Dept. of Mech. & Aero. Engineering, Princeton University. Near-wake streamwise velocity field with massless particles show results of new unstructured spectral element method.

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Transportable Molecular-Beam Mass Spectrometer

A powerful, versatile tool saves time and energy.

National Renewable Energy Laboratory (NREL), Golden, Colorado

Researchers at NREL are producing a transportable molecular beam mass spectrometer (TMBMS). This prototype, similar in performance and cost to a full-sized molecular beam mass spectrometer (MBMS), is one-fifth the size and requires only an electrical connection. Power consumption is cut in half. Most of the equipment fits on a rolling cart 1 m X 1.6 m (39 in. X 63 in.), so it can be readily transported by truck and set up at a new location.

NREL scientists developed the TMBMS because molecular beam mass spectrometry is an integral part of their development of several highly promising thermochemical conversion technologies. Other recent uses include continuous emission monitoring and solar detoxification research. Future continuous emission monitoring applications might include industrial stacks and hazardous waste incineration.

This new mobile version of the MBMS has tremendous potential. Conventionally, many research projects or commercial processes must rely on batch sampling, in which analysis is done after the fact and there is risk of altering samples in the process of collecting them, or settling for monitoring only certain compounds. The TMBMS can identify many chemical compounds at the same time, and can also handle high temperature, high pressure, moist or particulate-laden emissions, or product streams.

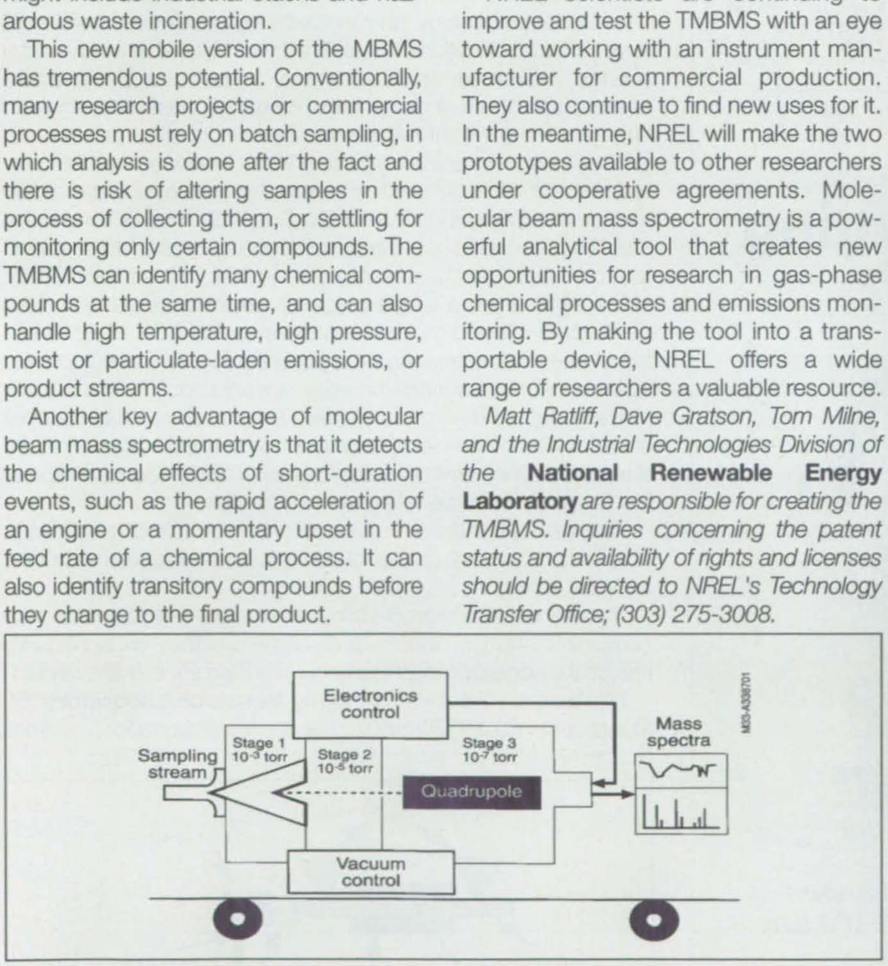
Another key advantage of molecular beam mass spectrometry is that it detects the chemical effects of short-duration events, such as the rapid acceleration of an engine or a momentary upset in the feed rate of a chemical process. It can also identify transitory compounds before they change to the final product.

The TMBMS measures the mass of individual molecules in a gas stream. To do this, it continuously extracts gases and vapors through a small nozzle, which then undergo free-jet expansion into the first of three vacuum chambers. A second nozzle extracts the core of the expanded sample, creating the molecular beam in the second vacuum chamber. Finally, the molecules are ionized in the third vacuum chamber, which contains one of two types of mass spectrometer.

One type, the time-of-flight spectrometer, functions by pulsing the ions into a tube and measuring how long it takes them to reach the detector. The other type, the quadrupole spectrometer, uses electronically controlled radio frequency and electrical fields that filter ions, one mass at a time, into the detector.

NREL scientists are continuing to improve and test the TMBMS with an eye toward working with an instrument manufacturer for commercial production. They also continue to find new uses for it. In the meantime, NREL will make the two prototypes available to other researchers under cooperative agreements. Molecular beam mass spectrometry is a powerful analytical tool that creates new opportunities for research in gas-phase chemical processes and emissions monitoring. By making the tool into a transportable device, NREL offers a wide range of researchers a valuable resource.

Matt Ratliff, Dave Gratson, Tom Milne, and the Industrial Technologies Division of the **National Renewable Energy Laboratory** *are responsible for creating the TMBMS. Inquiries concerning the patent status and availability of rights and licenses should be directed to NREL's Technology Transfer Office; (303) 275-3008.*



Schematic of the **Transportable Molecular Beam Mass Spectrometer** system. In stage 1, the pressure of the sample vapor stream drops dramatically, causing it to undergo free-jet expansion and adiabatic cooling. In stage 2, the core of the expanded sample is collimated by an orifice of 1.0-1.2 mm to form the molecular beam. In the mass spectrometer (here a quadrupole), the molecules of the beam are ionized and mass-analyzed.

LITERATURE SPOTLIGHT

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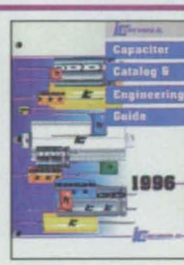


ILLINOIS CAPACITOR ANNOUNCES 1996 CATALOG

Illinois Capacitor's 208-page Catalog and Engineering Guide contains complete information on the company's aluminum electrolytic, film, ceramic, and power capacitors. It's all you need to make a knowledgeable capacitor selection. Available capacitance range, voltage ranges, operating temperature, case styles, IC-authorized distributor listings. Illinois Capacitor, Inc., 3757 W. Touhy Ave., Lincolnwood, IL 60645; Tel: 708-675-1760; Fax: 708-673-2850.

Illinois Capacitor, Inc.

For More Information Write In No. 382

Ferroelectric Phase Shifters for Electronic Scanning

These devices could yield low-cost scanning antennas for commercial applications.

Physical Sciences Directorate, Army Research Laboratory, Fort Monmouth, New Jersey

Electronic scanning antennas are functionally important in future commercial and military communications and radar systems. Most current radar scanning is mechanical, relying on a gimbal arrangement to physically rotate/elevate a radar antenna. Gimbaled scanning is slow, gravity-sensitive, and susceptible to mechanical failure. Electronic scanning is preferable because it is rapid and inertialess.

At present several technologies for phase shifting in electronic scanning are available against which the ferroelectric kind must compete. Among them are phase shifters using semiconductor devices and those using ferrite material. Semiconductor devices have an advantage in their small size, but are limited to small-signal applications, since high-power semiconductors have degraded microwave characteristics. Currently, most electronic scanning antennas are controlled by ferrite (magnetic) phase shifters. These are low-loss, and though they perform well, their size and cost limit the number of electronic scanning antennas in use today.

Ferroelectric phase shifters are significantly lower in cost and smaller in size than the ferrite kind. The former are compatible with planar technology, and those being developed at ARL will have *in situ* calibration to stabilize them against environmental change. Planar ferroelectric phase shifters are designed to operate as electrical delay lines, creating phase shift through changes in the velocity of the microwave signal.

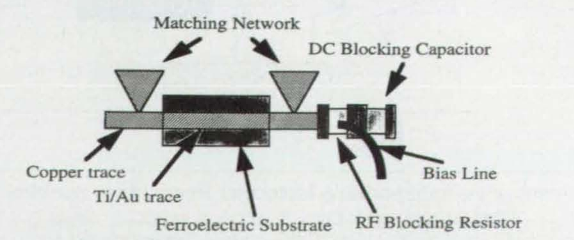
The planar ferroelectric phase shifter developed at ARL consists of a DC voltage block, matching transition, and metallized section of ferroelectric material ($Ba_xSr_{1-x}TiO_3$). The DC block and transition are part of the planar conducting circuit. More recently, techniques have been developed at ARL to produce multiple phase shifters on a single piece of ferroelectric material. This development will further reduce the size and cost of ferroelectric phase shifters, creating the potential for low-cost electronic scanning antennas for commercial applications.

Methods are being developed for real-time calibration of phase shifters, thus permitting dynamic compensation of phase due to aging or environmental stress. This is compatible with the future need for self-diagnosing systems.

These phase shifters are characterized by a 360° phase shift at 4 GHz, an insertion loss of 2.5 dB, and measurements of $5 \times 1 \times 0.3$ mm.

The performance characteristics of ferroelectric phase shifters are compatible with the industry state of the art. They will significantly reduce the size and cost of electronic scanning phased array radars.

This work was done at the **Army Research Laboratory**, *Ft. Monmouth, NJ 07703-5601. For further information, contact Richard Babbitt or William Drach, ARL; (908) 427-2284.*



Details of Ferroelectric Phase Shifter Section

Schematic showing details of **Ferroelectric Phase Shifter.**

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OMEGA UNIVERSAL GUIDE TO DATA ACQUISITION & COMPUTER INTERFACES™

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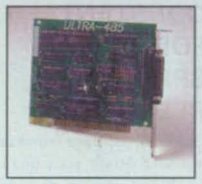

SINGLE-CHANNEL ASYNCHRONOUS SERIAL INTERFACE

OMEGA introduces the OMG-ULTRA-485 single-channel RS422/485 asynchronous serial interface. The OMG-ULTRA-485 is an ideal interface for factory automation equipment and PLC communication. The ULTRA-485 is perceived by the system to be an RS-232 port, so no special software drivers are required. Maximum data communication distance between PCs is 5000 ft., coupled with data rates up to 115K BPS.

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HIGH-SPEED ISOLATED TEMPERATURE/VOLTAGE INTERFACE

The OMB-MULTISCAN-1200 features channel-to-channel isolation for temperature and voltage measurements. Its high-speed scan rate allows the operator to scan temperature and voltage inputs at a rate of 147 channels per second. System expansion up to 744 channels is available through low-cost expansion chassis.

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HIGH-RESOLUTION PLUG-IN BOARD FOR IBM PCS AND COMPATIBLES

The new WB-ASC16 Series boards from OMEGA provide eight channels of 16-bit analog input for a wide variety of input types. Three models are available in this series. The WB-ASC16-TC accepts thermocouple, millivolt and voltage signals directly. The WB-ASC16-GP accepts both millivolt and voltage inputs. The WB-ASC16-RTD accepts RTD temperature sensors directly. All boards also include eight channels of digital I/O individually programmable as input or output.

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LIGHTNING/SURGE PROTECTORS GUARD AGAINST HIGH-VOLTAGE TRANSIENTS

The new CAT-22 Series lightning/surge sponges are designed to accommodate high voltage transients caused by lightning or other electrical disturbances that can easily destroy semiconductor junctions. The CAT-22 Series redirects these transients to earth ground. The protection circuits incorporate multiple separate stages of limiting high voltage transients: gas tubes, avalanche diodes, and MOV thyristors.

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DAS-1800 PLUG-IN BOARDS FOR IBM-COMPATIBLE COMPUTERS

The DAS-1800 Series plug-in boards feature continuous, high-speed, gap-free data acquisition under Windows or DOS. An on-board FIFO buffer and dual-channel DMA allow the acquisition of large amounts of data without losing data. The DAS-1800HC models feature 64 single-ended inputs of 32 differential inputs at up to 333 ksamples/sec. The DAS-1800ST has maximum acquisition at different gains, pre-post and about triggering, two analog outputs and digital I/O.

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VOLTAGE INPUT BOARD OFFERS PLUG-IN SOLUTION

The new model DAS-TC is an easy-to-use, highly accurate IBM PC and compatible plug-in solution for measuring thermocouple and voltage inputs. Up to 16 differential inputs are provided as well as one cold junction compensation (CJC) sensor input. Automatic calibration, gain selection, CJC thermocouple linearization conversion to degrees or volts and averaging are performed by an on-board microprocessor. To connect signals to DAS-TC, accessories provide screw terminal connections for all I/O lines.

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HIGH-SPEED DATA ACQUISITION FOR NOTEBOOK/DESKTOP PCS

The OMB-DAQBOOK-100 plug attaches directly to the parallel port on the PC. It can transfer data bi-directionally at up to 170 Kb/sec. The unit provides the following features: 16 analog inputs, expandable to 256; 2 analog outputs; 24 general-purpose I/O channels, expandable to 192; 16 high-speed digital inputs; and 5 frequency/pulse I/O channels.

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The World of Clamping Catalog 5/95 describes and illustrates toggle and special clamps with vertical and horizontal hold-down, straight-line, latch, and squeeze action. Spacing products, hydraulic devices, and CAD databases are covered, along with applications. De-Sta-Co, Box 2800, Troy, MI 48007; Tel: 800-245-2759.

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Colorful, 12-page brochure provides details on a line of stock and custom designed spring-powered devices for the OEM design engineer. Includes power springs, NEG'ATOR®constant force extension springs, constant force spring motors, prestressed spiral springs, stock spring-powered reels, motor assemblies, RW® laminar springs. Contains typical applications and selection guide. Ametek, U.S. Gauge Div., Sellersville, PA 18960; Tel: 215-257-6531; Fax: 215-257-3058.

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RUGGED MINIATURE SWITCH

The Series 70 is an environmentally rugged line of lighted and unlighted switches. Wet, dusty or oily duty. DPDT MOM or ALT switch actions. Mounts on 0.700" centers with 0.880" depth. Lighted pushbuttons use T-1 MFB lamps. Variety of display types, colors, and styles. StacoSwitch, 1139 Baker St., Costa Mesa, CA 92627; Tel: 714-549-3041; Fax: 714-549-0930.

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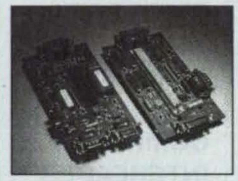

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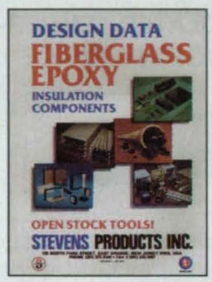

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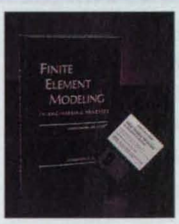

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NEW PRODUCTS

New High-Speed A/D Converter Family

Micro Networks, Worcester, MA, announces a new family of high-speed analog-to-digital (A/D) converters with a wide range of commercial and military applications. Two of the three models, the MN5930 and MN6250, have a sampling rate of 30 MHz; rate for the MN5925 is 20 MHz. The MN5925 and MN5930, monolithic devices packaged in a plastic DIP configuration, operate over the 0-70 °C temperature range; the MN6250, a mixed-signal multichip circuit, has a T/H amplifier, reference, and timing circuitry in a single 32-pin ceramic dip package.

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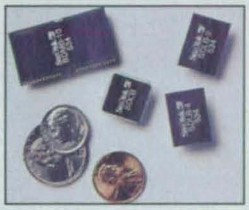

Embedded ATA Data Storage System

SanDisk Corp., Santa Clara, CA, introduces the Flash Chipset, which it calls the world's smallest embedded solid-state ATA data storage system. The device provides product developers with very low-power, high-capacity storage for integration into lightweight mobile electronics. It is available in 2, 4, and 10-MB capacities, and with full ATA/IDE disk drive compatibility can be designed into many platforms and operating systems.

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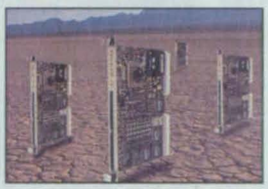

VME Waveform Capture Board

The VDA500 waveform capture board from Signatec, Corona, CA, has an analog bandwidth of DC-500 MHz, an 8-bit 500-MHz digitizer, 256 kilobytes of on-board memory, and a data transfer rate of 200 MB/s. Memory is expandable to 1 gigabyte or more with external memory modules. The VDA500 has two input channels and a multiplexer to select one of the two as the digitizing source. On-board crystal clock circuitry makes possible selecting 1 of 28 digitizing frequencies between 312.5 kHz-500 MHz.

For More Information Write In No. 779

Boards for Processing Large Data Banks

The CV 6 range of digital signal processor boards from Spectrum Signal Processing Inc., Burnaby, B.C., Canada, provide an easily configurable range of VME platforms for applications requiring precision analysis of large amounts of data. Radar and sonar applications will exploit the high-speed CV6 VME64 interface by transferring large data blocks to the 64-MB shared DRAM, while imaging applications benefit from the broadcast write feature. The CV6 board is available with six memory options.

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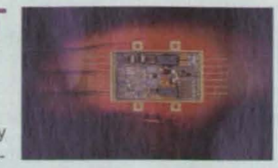

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The high-density ADDC02805S 28-V-to-5-V (20 A) DC-to-DC converter from Analog Devices, Norwood, MA, has on-board EMI filtering, input transient protection, and system-level functions to simplify complex power-supply systems. The 2.5" × 1.5" hybrid devices guarantee up to 100 W of continuous output power over a wide range of input conditions (16-50 V DC). Temperature operating range, factory testing, and price vary for three versions: industrial grade, ruggedized industrial grade, and MIL-STD-883D tested.

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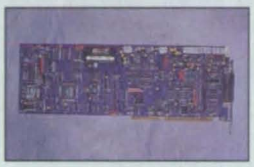

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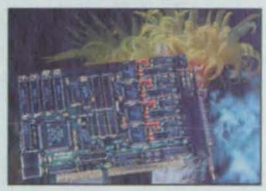

Floating-Point Digital Signal Processor

Signalogic, Dallas, TX, offers the Sig32C-8^{x} 32-bit floating-point digital signal processor with up to 640k-x-32 SRAM, and eight channels of analog I/O on a 7.5-in. PC plug-in board. Each channel has 16-bit analog-to-digital and digital-to-analog converters and programmable input gain, output attenuation, and sampling rate. Sigma-delta technology gives the channels anti-aliasing and reconstruction filters for high out-of-band rejection and linear phase.

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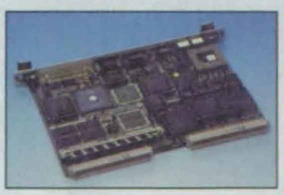

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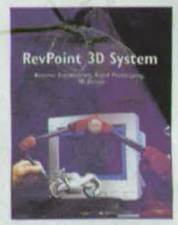

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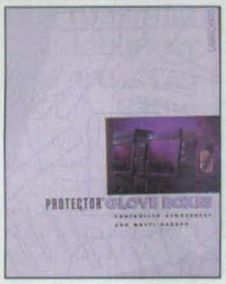

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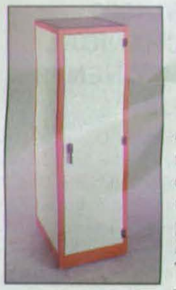

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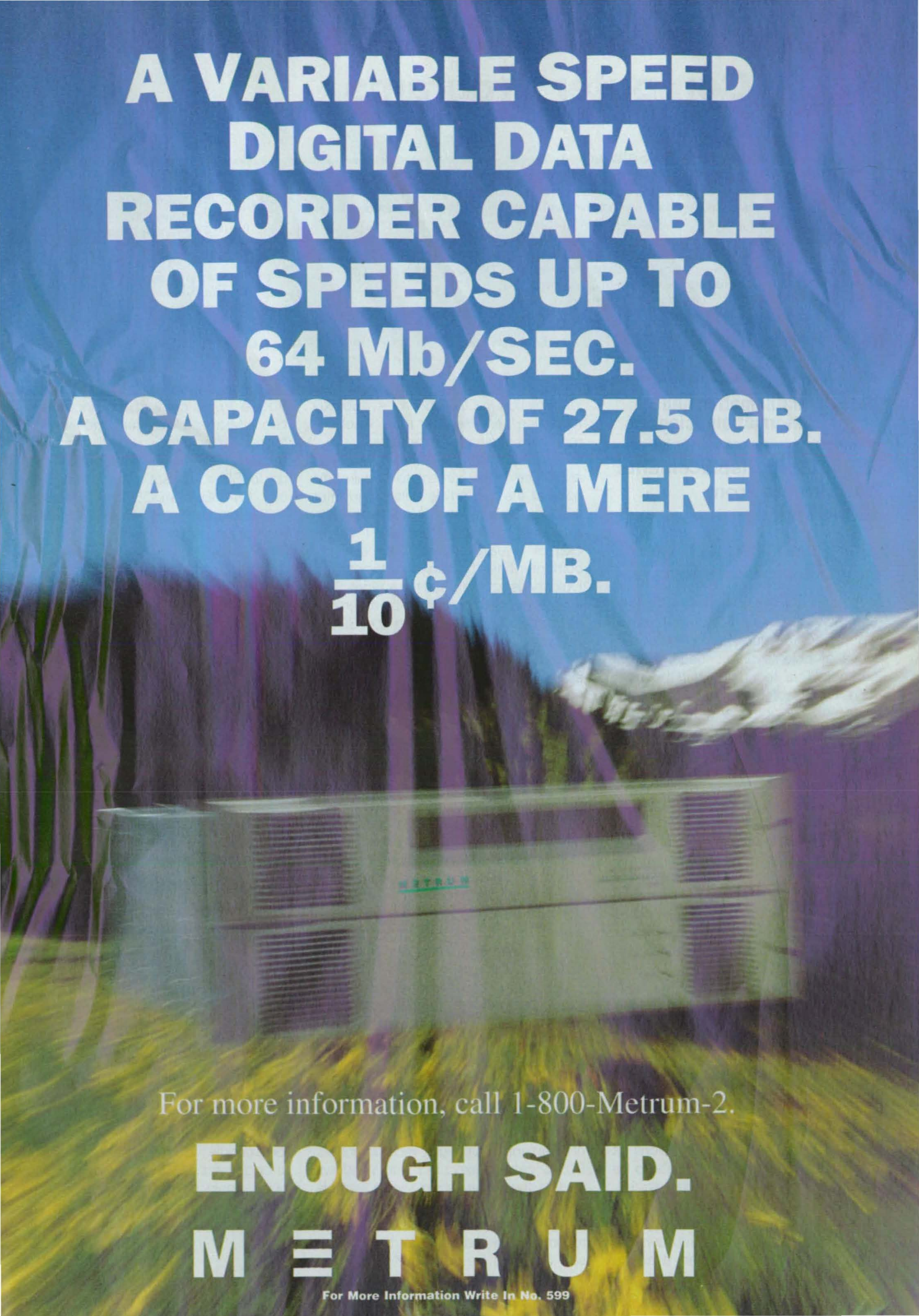
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Mathematics and Information Sciences

Computing Displacements and Strains From Video Images

There is no need for custom or expensive equipment.

Subpixel digital video image correlation (SDVIC) is a technique for measuring in-plane displacements on the surfaces of objects under loads, without contact. This technique can be used for analyses of experimental research specimens or actual service structures of virtually any size or material. Only minimal preparation of test objects is needed, and there is no need to isolate test objects from minor vibrations or fluctuating temperatures. The technique is implemented by the SDVIC software, which produces color-graduated, full-field representations of in-plane displacements and their partial derivatives with respect to position along both principal directions in each image plane. From these representations, linear strains, shear strains, and rotation fields can be determined.

The SDVIC software is based upon an algorithm for locating small regions of a random pattern after the pattern has been deformed. The SDVIC software determines values for in-plane displacements and strains by correlating the positions of subsets of pixels in the original image with those in the deformed image on the basis of pixel gray levels in the digitized versions of the images. The sizes of subsets to be pattern-matched can be customized, thus enabling the correlation of many random patterns. Several techniques, including a coarse-fine search and the Newton-Raphson method, are available for subset pattern matching. A bilinear interpolation routine provides subpixel resolution necessary for most displacement and strain measurements.

To utilize SDVIC, one needs a black-and-white video camera to acquire images of the test article before and after loading. Camera-lens combinations can be altered to enable analyses of test articles of virtually any size. A personal-computer-based video circuit board is typically used to digitize the images. The images are then correlated by a personal computer equipped with the SDVIC software. All of the components needed for a typical system are commercially available. There is no need for custom equipment, which can be expensive or difficult to find.

In order to correlate properly images based upon subset gray-level patterns, one must have a characteristic pattern on the surface of the test article. This pattern can be one that occurs naturally, (for example, the microscopic grains and grain boundaries of a metal as viewed under magnification), or the pattern can be applied by dusting the specimen with fine particles or spraying the specimen with white and black spray paint. Application of a pattern typically requires only a few minutes and a few dollars for several specimens.

SDVIC is written in C language for IBM PC-series and compatible computers running MS-DOS. The minimum requirements for execution of SDVIC include an 80386 processor, Microsoft Windows v3.1, an SVGA monitor, 2MB of random-access memory (RAM), and 5MB of swap space. For best results, an 80486/66-MHz processor, 8MB of RAM, and 32MB of swap space are highly recommended. SDVIC can be executed with Windows v3.1 in the enhanced mode. A sample executable code is provided on the distribution medium. If there is need to recompile the source code, then Microsoft Software Developers Kit v3.1 and Microsoft C compiler v6.0 are required. An electronic copy of the documentation in Microsoft Word for Windows v2.0b format is included on the distribution medium. The standard distribution medium for SDVIC is a set of four 3.5-in. (8.89-cm), 1.44MB, MS-DOS-format diskettes.

This program was written by Stephen R. McNeill of the University of South Carolina, Samuel S. Russell of **Marshall Space Flight Center**, *and Matthew D. Lansing of the University of Alabama in Huntsville. For further information,* ***write in 77*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-26289.

Physical Sciences

Program Models a Laser Beam Focused in an Aerosol Spray

A Monte Carlo analysis is performed on packets of light.

The Program for the Analysis of a Laser Beam Focused Within an Aerosol Spray (FLSPRY) was developed for theoretical analysis of the propagation of a laser pulse optically focused within an aerosol spray. FLSPRY can be applied, for example, to analyze a laser ignition arrangement in which a focused laser pulse would be used to ignite a liquid aerosol fuel spray. Scattering and absorption of laser light by the individual

(continued on page 73)


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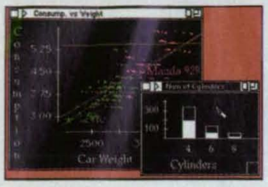

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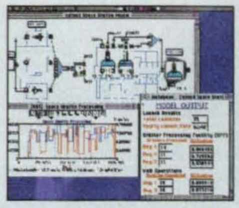

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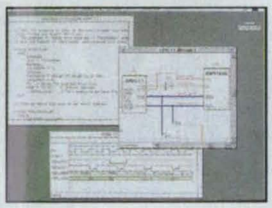

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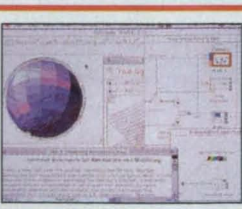

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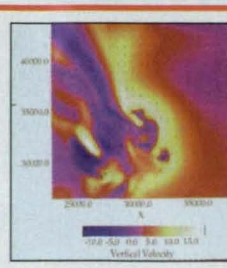

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(continued from page 70)

aerosol droplets are evaluated by use of electromagnetic Lorenz-Mie theory.

Initially, propagation of a laser beam is modeled by use of a simple modified paraxial-ray theory, which would limit applications to relatively "optically thin" sprays. To keep from limiting the application of the program to "optically thin" sprays, a Monte Carlo analysis of the laser beam has been adapted to FLSPRY. The Monte Carlo analysis follows individual "light packets" through a dense spray of defined thickness and composition.

The spray is assumed to be monodisperse and homogeneous, and the light packets enter along the same axis with perpendicular incidence. The Monte Carlo algorithm was modified to account for the spatial variation of intensity and the variable angle of incidence at the illuminated side of the spray. An appropriately weighted Monte Carlo decision is used to determine the position of incidence for each light packet. After a large number of attempts, a Gaussian intensity profile is generated.

Inputs to FLSPRY include the volume fraction of liquid, average size of droplets, droplet-size distribution, laser wavelength, laser-pulse energy, laser-pulse duration, focal length of the lens, diameter of the beam incident on the lens, and the choice of aerosol liquid and surrounding gaseous medium. Other inputs include Monte Carlo analysis indicator, radius (cm) for Monte Carlo analysis, location of Monte Carlo analysis (cm) relative to the lens, number of Monte Carlo attempts, and random-number-generator seed for Monte Carlo analysis. Also necessary for Monte Carlo analysis are the x_{max}, x_{min}, y_{max}, and y_{min} thicknesses of the spray (cm). The output of the computer program includes, as a function of spatial position along the laser propagation axis within the spray, the laser-pulse intensity and energy, the overall volumetric absorption of laser energy by the aerosol liquid and by the gaseous medium, and the overall average temperature rise of the aerosol liquid and of the gaseous medium.

FLSPRY is written in FORTRAN 77 for both UNIX-based computers and DEC VAX-series computers. FLSPRY requires a compiler that supports NAMELIST input. The VAX version of the program (LEW-16051) has been successfully implemented on DEC VAX-series computers running VMS v5.5. The UNIX version of the program (LEW-16065) has been successfully implemented on SGI IRIS-series computers running IRIX 5.2, and DEC ALPHA AXP-series computers running OSF/1. The author of the program has also successfully implemented FLSPRY on IBM RS/6000-series computers running AIX v3.2, using the FORTRAN 77 v2.03 compiler. The standard distribution medium for the VAX version of FLSPRY is a 1,600-bit/in. (630-bit/cm), 9-track magnetic tape in DEC VAX BACKUP format. It is also available on a TK50 magnetic-tape cartridge in DEC VAX BACKUP format. The standard distribution medium for the UNIX version of FLSPRY is a 0.25-in. (6.35-mm) streaming-magnetic-tape cartridge (Sun QIC-24) in UNIX tar format. Upon request, the UNIX version of FLSPRY can be provided in UNIX tar format on alternate media. FLSPRY was released in 1994.

This program was written by J. P. Barton of the University of Nebraska in Lincoln for **Lewis Research Center**.

For further information on LEW-16051, ***write in 32*** *on the TSP Request Card.*

For further information on LEW-16065, ***write in 33*** *on the TSP Request Card.*

LEW-16051/65

Mechanics

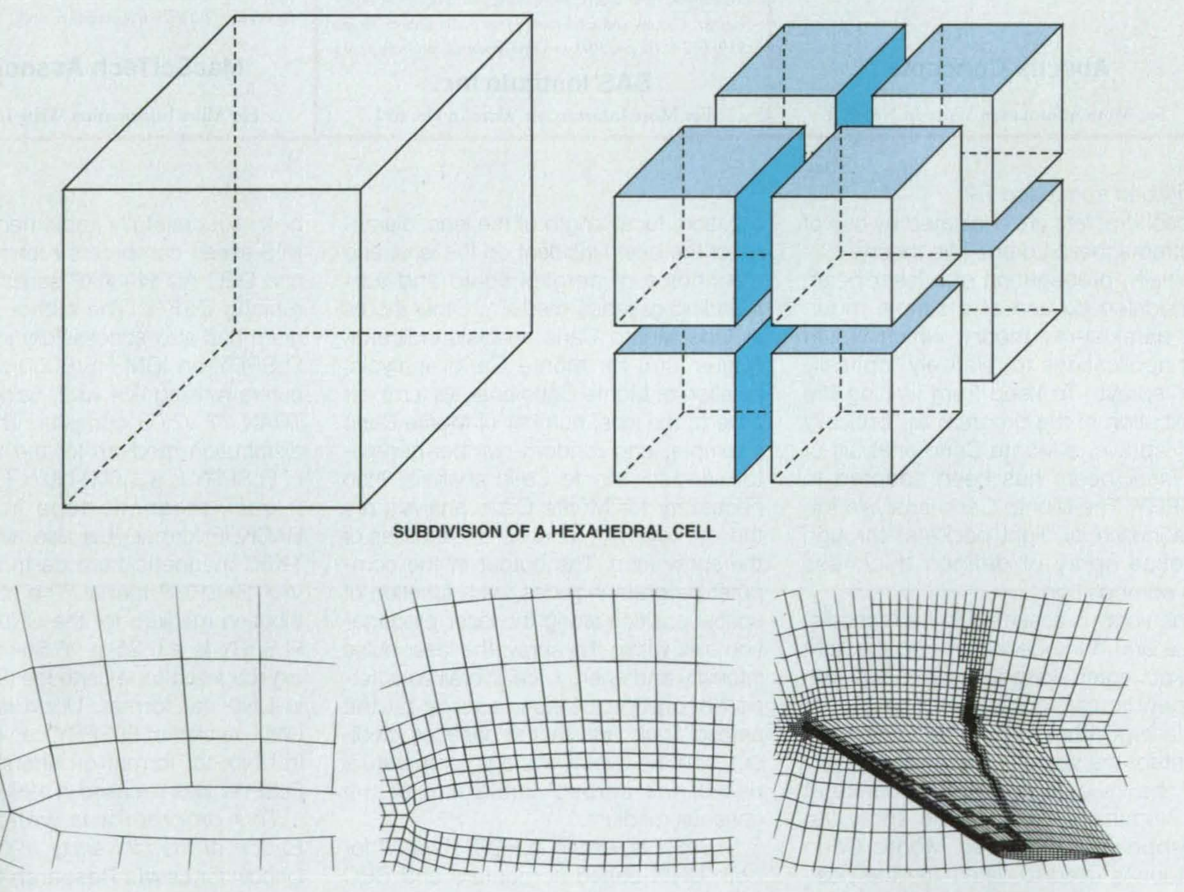
Refinement of Hexahedral Cells in Euler Flow Computations

Computational grids are refined where necessary to resolve details more accurately.

Ames Research Center, Moffett Field, California

The Topologically Independent Grid, Euler Refinement (TIGER) computer program solves the Euler equations of three-dimensional, unsteady flow of an inviscid, compressible fluid by numerical integration on an unstructured hexahedral coordinate grid that can be refined where necessary to resolve shocks and other details. (As used here, "unstructured" means arbitrarily and/or complicatedly shaped, usually to fit an irregularly shaped body in the flow field.) The Grid Interactive Refinement and Flow-Field Examination (GIRAFFE) computer program was written in conjunction with the TIGER program to display the computed flow-field data and to assist the researcher in verifying specified boundary conditions and refining the grid.

The TIGER program is based on Jameson's FL057 program, which solves the Euler equations on a structured grid by use of a finite-volume, four-stage Runge-Kutta numerical-integration algorithm. The development of TIGER involved modifications to incorporate conservative calculations of mass, momentum, and energy fluxes across the faces of multiply connected grid cells. The unstructured-grid nature of TIGER makes it amenable to local refinement of the grid, as specified by the researcher.



SUBDIVISION OF A HEXAHEDRAL CELL

Original Grid at the 50-Percent-of-Span Plane

Grid at the 50-Percent-of-Span Plane After the Second Step of Refinement

Part of the Final Refined Grid

ASPECTS OF REFINEMENT OF THE COMPUTATIONAL GRID ABOUT AN AIRPLANE WING

Hexahedral Cells are subdivided, each into eight smaller cells, as needed to refine the computational grid in regions of high flow gradients.

Each grid cell can be split into eight smaller cells (see figure). If further refinement is needed, the smaller cells can be subdivided similarly. Refinement of the grid appropriate to each flow-field condition and tailored to capture shocks or other specific flow features can be based on a variety of criteria; for example, the ratio between the local and free-stream total pressures, the difference between the maximum and minimum pressures in the vicinity, or the preliminarily calculated location of a shock.

The TIGER program takes about the same amount of time to compute a flow as do conventional flow-simulating programs that solve the Euler and Navier-Stokes equations on structured (that is, regular) grids. The TIGER program involves the use of simple, straightforward programming techniques to take advantage of the vector-processing capabilities of the CRAY Y-MP computer. The TIGER program requires approximately five times more memory per grid point than a conventional structured-grid program does, but in TIGER, it is not necessary to refine the grid throughout the entire flow domain. When the refinement of the grid is based on flow parameters specified by the researcher, points of the resulting grid are usually distributed more appropriately for the problem, yielding a net decrease in the total memory required.

This work was done by John E. Melton and Gelsomina Cappuccio of **Ames Research Center** *and Scott D. Thomas of Sterling Federal Systems. Further information may be found in AIAA paper 91-0637: "Unstructured Euler Flow Solutions Using Hexahedral Cell Refinement."*

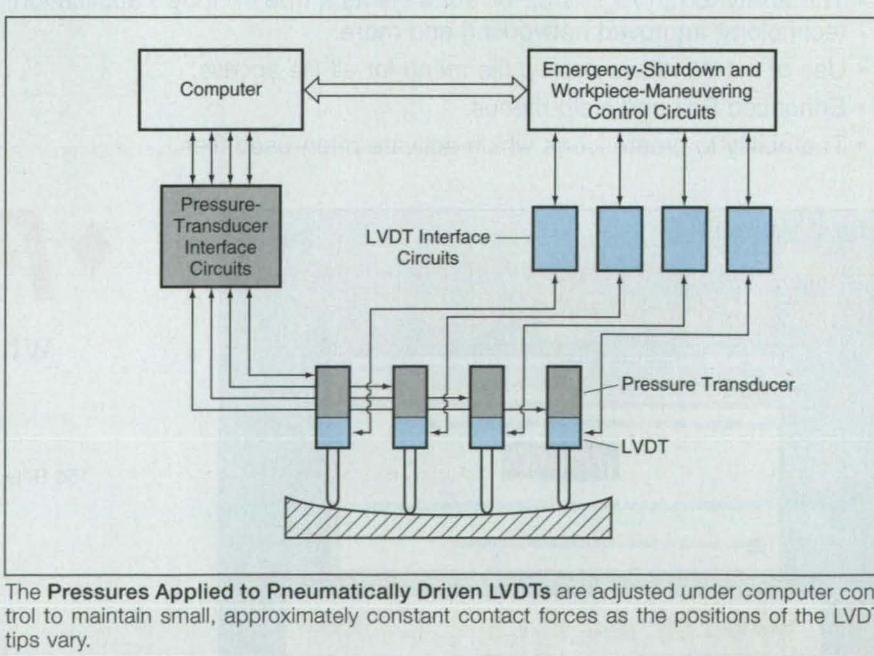
Copies may be purchased [prepayment required] from AEROPLUS, Burlingame, California 94010, Telephone No. (800) 662-2376, Fax No. (415) 259-5047. ARC-13077

Sensing Position With Approximately Constant Contact Force

LVDTs are held lightly against the surface to be measured.

Marshall Space Flight Center, Alabama

A computer-controlled electromechanical system uses a number of linear variable-differential transformers (LVDTs) to measure the axial positions of selected points on the surface of a lens, mirror, or other precise optical component with a high finish. The system maintains the contact force of each probe at a level between the weights of 9 and 13 grams: this level of force is just large enough to ensure consistent measurements but not so large as to cause damage to the surface when the probe is compressed or extended during axial positioning of the optic, over an axial range of 7 mm, between measurement positions in contact with the optic surface when the optic is rotated between measurement positions.



The **Pressures Applied to Pneumatically Driven LVDTs** are adjusted under computer control to maintain small, approximately constant contact forces as the positions of the LVDT tips vary.

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The contact tip of each LVDT is a 4-mm ruby ball. Each LVDT is spring-loaded in retraction from the surface to be measured. The probe is driven pneumatically, against the spring loading, into contact with the surface. The pneumatic pressure applied to each probe is sensed and adjusted via an electromechanical pressure transducer. Operating under computer control, the transducers for all the probes maintain the pressures that produce the required contact forces.

The output of each LVDT is a voltage indicative of the position of its tip. During the initial approach to the surface to be measured, the probes are retracted. The pneumatic pressure driving each probe is increased in steps to extend the probe in steps of 0.006 in. (≈0.15 mm). Eventually, the position reading from a probe stops increasing, signifying that the probe has made contact with the surface. Thereafter, the computer maintains the pressure at the level that corresponds to the required contact force. In computing this pressure, the computer accounts for the increase in spring retraction force with increasing extension of the tip or decrease in spring retraction force with compression of the tip.

This work was done by Jay Sturdevant of Hughes Aircraft Co. for **Marshall Space Flight Center.** *For further information,* ***write in 49*** *on the TSP Request Card.*

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act {42 U.S.C. 2457(f)} to Hughes Aircraft Co. Inquiries concerning licenses for its commercial development should be addressed to:

Hughes Aircraft Co.
Attn: Jay Sturdevant
7200 Hughes Terrace
P.O. Box 45066
Los Angeles, CA 90045-0066

Refer to MFS-28936, volume and number of this NASA Tech Briefs *issue, and the page number.*

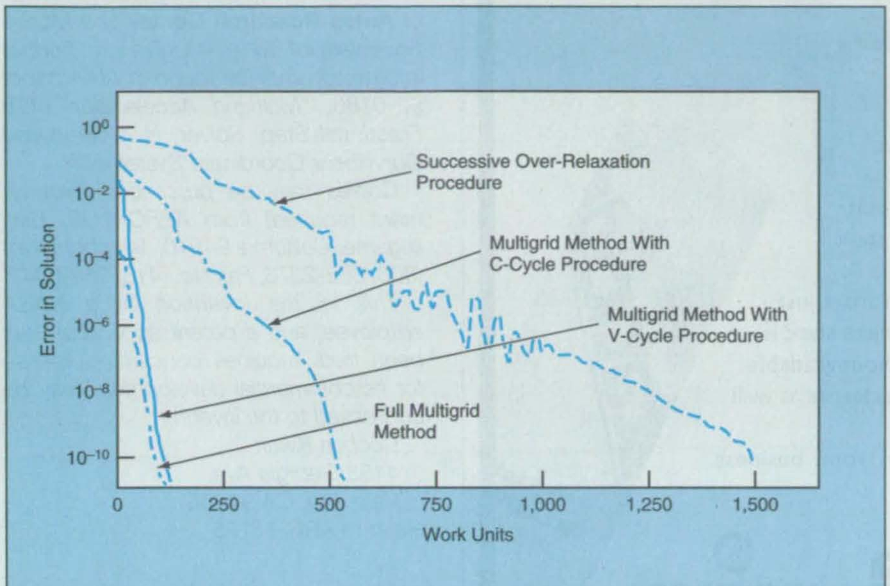
Multigrid, Fractional-Step Computation of Flow

Computation of incompressible flow to high resolution takes less time.

Ames Research Center, Moffett Field, California

The speed of a computer code that solves the three-dimensional Navier-Stokes equations of flow of an incompressible fluid by the fractional-step method has been increased significantly by use of multigrid procedures. In the specific version of the fractional-step method, the equations are solved on a general nonorthogonal curvilinear coordinate grid, using volume fluxes (instead of velocities). At each time step, computations are performed in two fractional steps. In the first fractional step, the equations of conservation of momentum are solved by use of the gradient of pressure from the previous time step via an explicit approximate-factorization method, yielding an approximate flow field that does not satisfy the equation of conservation of mass. In the second fractional step, a discrete Poisson-like equation with Neumann-type boundary conditions, formed by combining the equations of conservation of momentum and mass, is solved iteratively.

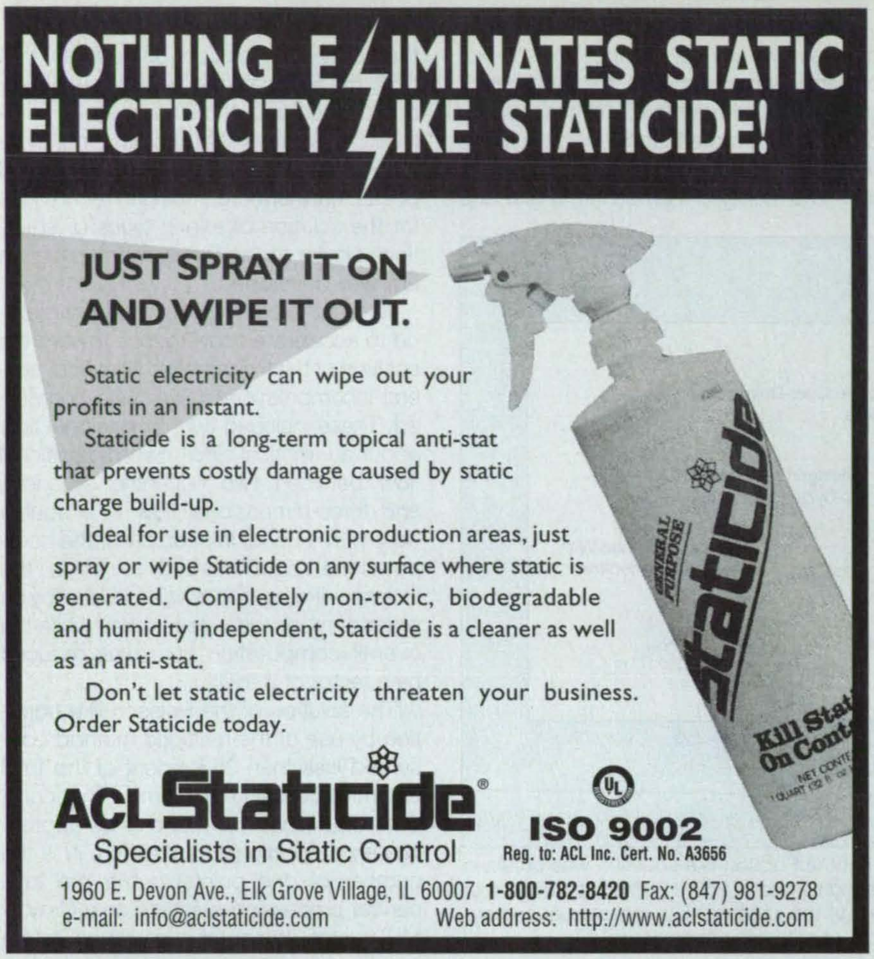
The number of arithmetic operations of, and therefore the time consumed by, the iterative solution of the Poisson-like equation increases with the number of grid points; heretofore, it has usually amounted to more than 80 percent of the total time of a fractional-step computation. The multigrid method is the only one that provides solution procedures that both are applicable to general curvilinear coordinates and entail numbers of arithmetic operations that increase no more than linearly with the number of grid points. Furthermore, multigrid techniques for the solution of elliptic types of equations similar to the Poisson-like equation are well developed.



This **History of Convergence** toward the solution of the Poisson-like equation was obtained in a computation of flow between eccentric cylinders on a grid of 256 × 256 points, using four different solution procedures. A work unit (the scale of the abscissa) is a measure of computational effort, essentially proportional to the number of arithmetic operations.

To test the ability of the multigrid method to accelerate convergence toward the solution of the Poisson-like equation, several incompressible flows were computed. These included two-dimensional flow about an elliptical airfoil, two-dimensional flow between two eccentric cylinders, and three-dimensional flow in a square duct with a bend. In each case, the computational time needed to solve the Poisson-like equation was reduced by an order of magnitude (see figure), while the overall computation time was reduced by a factor of 3 to 4.

The solution of the Poisson-like equation by use of the multigrid method consumed less than 25 percent of the total central-processing-unit time. The computational work was found to be approximately proportional to N (where N is the number of grid points), while the total central-processing-unit time on a Cray Y-MP vector computer was found to be



approximately proportional to $N^{0.75}$. Thus, it appears that the combination of multigrid and fractional-step methods provides a viable alternative for the computation of complicated flow fields with very large numbers of grid points.

This work was done by Dochan Kwak of **Ames Research Center** *and Moshe Rosenfeld of Tel Aviv University. Further information may be found in AIAA paper 92-0185, "Multigrid Acceleration of a Fractional-Step Solver in Generalized Curvilinear Coordinate Systems."*

Copies may be purchased [prepayment required] from AEROPLUS, Burlingame, California 94010, Telephone No. (800) 662-2376, Fax No. (415) 259-5047.

This is the invention of a NASA employee, and a patent application has been filed. Inquiries concerning license for its commercial development may be addressed to the inventor:

Dochan Kwak
4153 Georgia Ave.
Palo Alto, CA 94306
Refer to ARC-13196.

Bearings Incorporating Deadband Rollers

Marshall Space Flight Center, Alabama

Bearings in a high-pressure turbopump have been redesigned to incorporate rollers that allow limited axial motion within a small deadband. The design does not permit radial deadband motion, which is undesired. The axial deadband motion would be used for rotor-thrust-balance control. The axial-deadband rollers would be supported by a multisided bearing carrier. This design would eliminate some nonlinearities in the dynamics of the pump rotor and assist in suppressing vibrations at harmonics of the frequency of rotation.

This work was done by Guy V. Gualtieri of United Technologies for **Marshall Space Flight Center**. *To obtain a copy of the report, "Bearing Deadband Rollers,"* ***write in 27*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-28914.

Industry Focus:
Motion Control/Positioning Equipment

Control of a Serpentine Robot for Inspection Tasks

In keeping with its serpentine character, the robot moves with a slither.

NASA's Jet Propulsion Laboratory, Pasadena, California

An efficient, robust kinematic control scheme has been developed to control a serpentine robot that is designed to inspect a complex structure (see figure). The control scheme takes full advantage of the multiple redundant degrees of freedom of the robot to provide considerable dexterity for maneuvering through a workspace that can be cluttered with stationary obstacles at initially unknown positions. Appropriately to the serpentine configuration of the robot, the control scheme produces a slithering motion.

The robot includes an anthropomorphic robot arm mounted on a platform with one degree of freedom (the platform can translate along a track). The anthropomorphic robot arm includes joint actuators that provide 7 degrees of freedom. Mounted at the tip of the anthropomorphic robot arm is a 6-jointed appendage with 12 degrees of freedom. Thus, there is a total of 20 degrees of freedom.

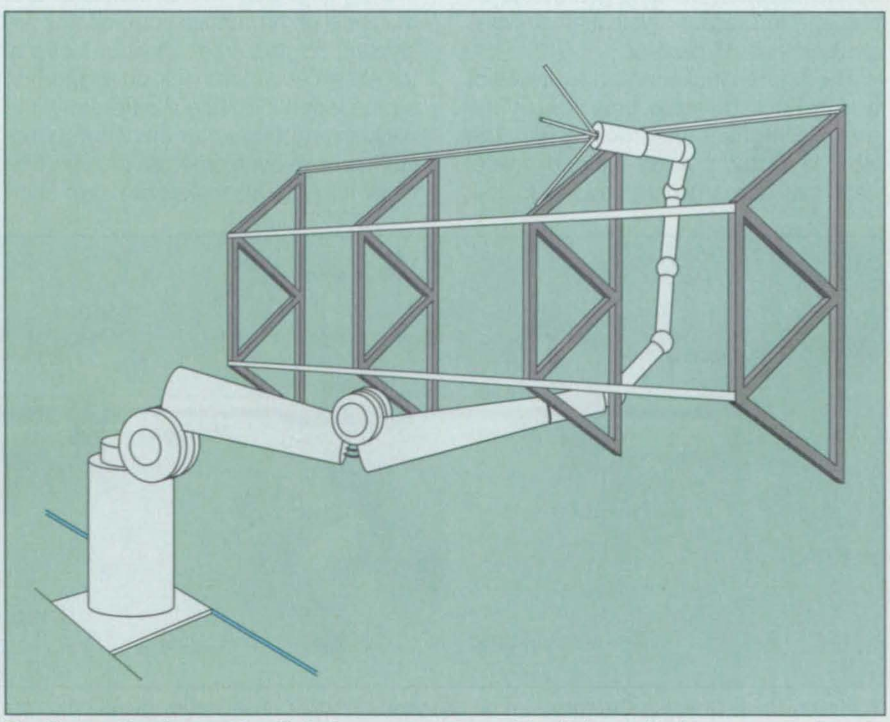
The control scheme is based partly on a version of the configuration-control concept, which has been discussed in a number of prior articles in *NASA Tech Briefs*. To recapitulate: A robot has n degrees of freedom (in this case, n = 20). The basic task is to make the tip of the end effector (the hand at the tip of the manipulator arm) follow a prescribed trajectory in m-dimensional coordinates (where $m < n$). The $r = n–m$ redundant degrees of freedom are used simultaneously to perform an additional task, which can be specified by the user and can include reaching around obstacles, avoiding collisions with objects in the workspace, maintaining one or more links of the manipulator arm in a desired pose, and/or optimizing the overall kinematics. The additional task is represented by a set of kinematic functions that, in effect, define the trajectory in the redundant degrees of freedom.

The end effector of the serpentine robot is instrumented with proximity sensors to detect obstacles and thereby provide for control feedback to prevent collisions between the end effector and the obstacles. It is also necessary to prevent such collisions for all of the interconnected links of the robot arm. The resulting motion-control problem is complex; to cope with the complexity, the problem is decomposed into two subproblems.

The first subproblem is that of the basic task of finding a collision-free path for the end effector, using the readouts from the end-effector sensors and one of the many available mobile-robot-control algorithms. The second subproblem is that of the additional task of making the 6 joints of the appendage follow the same path as that taken by the tip of the end effector so that joints and the links between them also do not collide with obstacles: this amounts to specification of a slithering motion, in which each joint is required to follow the preceding one, the two joints being separated from each other by the length of the intervening link. This requirement is expressed mathematically as a set of kinematic constraints on the 12 degrees of freedom of the appendage.

The equations for the position of the end effector in terms of the joint angles (equations of forward kinematics) and the equations for the velocity of the end effector in terms of the joint angles and rates of change of these angles (equations of forward differential kinematics) are combined with the corresponding equations for the joints following the end effector to obtain an augmented set of equations, and the augmented set of equations of differential kinematics is solved by use of a damped-least-squares algorithm to obtain the joint-angle rates, which are then integrated in time to obtain the joint angles, as a function of time, that result in the desired trajectories.

It has been proposed to extend this control scheme to cope with an environment in which the obstacles are



The **Serpentine Inspection Robot** maneuvers to avoid collisions with the struts of a truss.

not necessarily stationary. For this purpose, proximity sensors would be mounted on all of the links. The proximity-sensor information regarding the locations of obstacles would be compressed into a set of kinematic inequality constraints. The motion-control algorithm would be modified to ensure that these inequality constraints are satisfied, thereby ensuring avoidance of obstacles.

This work was done by Homayoun Seraji of Caltech and Richard D. Colbaugh and Kristin L. Glass of New Mexico State University for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 59*** *on the TSP Request Card. NPO-19506*

Non-Back-Drivable Gearboxes With Greater Efficiencies

Components are designed so that input torques reduce frictional losses.

NASA's Jet Propulsion Laboratory, Pasadena, California

Non-back-drivable gearboxes with power-transfer efficiencies greater than those of conventional non-back-drivable gearboxes are undergoing development. The greater efficiencies are made possible by a novel design concept that utilizes the input torques in such a way as to reduce frictional losses.

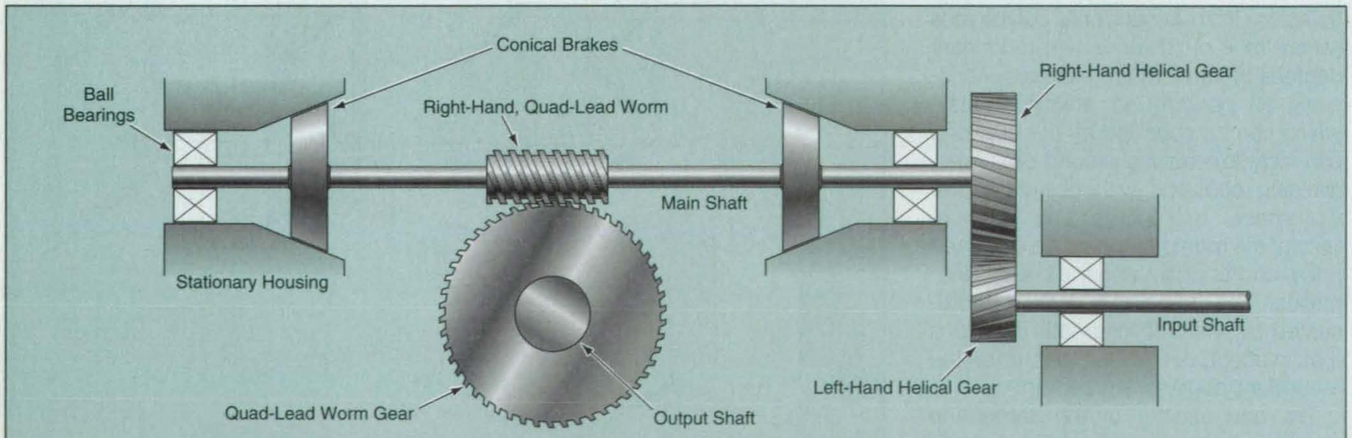
A non-back-drivable gearbox is one that locks itself when input power is not supplied: it transmits torque from a high-speed, low torque input shaft to a low-speed, high torque output shaft, but does not transmit torque from the output shaft back to the input shaft. Typical conventional non-back-drivable mechanisms include worm gears and lead screws. All non-back-drivable gearboxes rely on friction. To make a gearbox non-back-drivable according to the conventional design concept, it is necessary to make the power lost to friction equal to or greater than the output power. Consequently, the theoretical maximum efficiency of a conventional non-back-drivable gearbox is 50 percent. In practice, typical efficiencies are less than 35 percent.

The figure illustrates an example of a non-back-drivable gearbox of the present higher-efficiency type. The input shaft turns a left-handed helical gear that drives a right-handed helical gear on a main shaft. A quad-lead (that is, quadruple-thread), right-handed worm on the main shaft drives a quad-lead worm gear on the output shaft. Con-sidered by itself, without the braking mechanism described below, this particular worm-gear mechanism is back-drivable, with an efficiency of 80 to 90 percent whether the worm or the worm gear is being driven.

The main shaft turns in ball bearings that allow some small axial movement. Disks with outer conical braking surfaces are mounted near the bearings at both ends of the shaft. At either extreme of the small axial movement, the conical braking surface on one of the disks makes contact with a mating stationary conical braking surface. When a torque is applied to the output shaft in an attempt to back-drive the gearbox, the worm gear exerts a back-driving torque on the worm; it also exerts an axial force on the main shaft, thereby pushing the main shaft axially until one of the conical brakes engages. The dimensions and materials of the various components are chosen so that the braking frictional torque exceeds the back-driving torque on the worm. To state it differently, the back-driving torque on the worm is not sufficient to overcome the braking frictional torque. This makes the main shaft non-back-drivable, even though the worm-gear mechanism would otherwise be back-drivable.

The reason for using a left-handed driving and a right-handed driven helical gear at the input is that they utilize the input torque in a manner that reduces the braking friction. The engagement of these gears gives rise to an axial thrust on the main shaft; this thrust is proportional to the input torque and in the direction opposite that of the axial thrust exerted by the load or attempted-back-driving torque. The force of engagement of the conical braking surfaces and thus the braking torque are reduced accordingly. With less braking friction to overcome, a greater proportion of the input power is transmitted to the output. Of course, the success of this concept depends in part on choosing the design parameters so that the torque transmitted from the input shaft to the main shaft is great enough to overcome the remaining braking friction but not so great as to drive the shaft to the opposite extreme position in which the other brake engages.

This work was done by Timothy R. Ohm of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 9*** *on the TSP Request Card. NPO-19322*



This **Non-Back-Drivable Gearbox** can be designed to exhibit an efficiency greater than the theoretical maximum of 50 percent for conventional non-back-drivable gearboxes. Typical theoretically achievable efficiencies appear to exceed 70 percent.

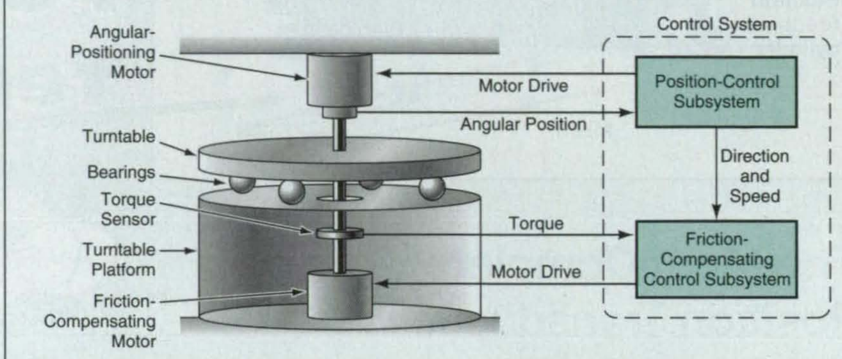
Compensating for Friction in a Rotation-Testing Turntable

A motor would apply a torque calculated to cancel the frictional torque.

Lewis Research Center, Cleveland, Ohio

A proposed turntable for testing heavy equipment in rotation would be driven by two motors (see figure). One of the motors would operate under actuator commands from a position-control subsystem; it would rotate the turntable to commanded angular positions according to the specifications for a test. The other motor would operate under actuator commands from a friction-compensating control subsystem; this motor would approximately cancel the effect of frictional torque in and on the turntable, so that the equipment could be tested as though in a nearly frictionless environment.

The turntable was conceived for testing angular-positioning systems for spacecraft solar arrays that weigh several tons; it would be equally useful for effectively frictionless rotational testing of heavy terrestrial equipment. The turntable and its control system would be used instead of any of a variety of low-friction supporting mechanisms like tethers, air bearings, and floatation devices. Although the electronic control system of the turntable would be



The **Turntable Would Bear a Massive Load** for rotational testing. The friction-compensating motor would apply a torque calculated to counteract the frictional torque.


SERVO TUNING
CONTROL PANEL
TWEAK-O-METER
LOAD COMPENSATOR
ON
OFF

complex, the turntable would be mechanically simpler than the other mechanisms and it would be more stable. The turntable would also enable testing under more realistic conditions.

The friction-compensating control subsystem would have to be calibrated to make the friction-compensating motor apply the opposite of the frictional torque as a function of the speed of rotation, independent of inertial forces. For this purpose, the positioning motor would be turned off and the frictional torque would be measured at a large number of constant speeds over the range of possible speeds. The resulting data on frictional torque vs. speed would be recorded in an electronic read-only memory (ROM) in the friction-compensating control subsystem. Thereafter, during a test on the turntable, the friction-compensating control subsystem would command the motor to apply a torque opposite the recorded frictional torque as a function of speed.

Static friction, which in general is greater than dynamic friction, would also be measured and stored. With the turntable at rest, the torque applied by the friction-compensating motor would be slowly increased until the turntable would just begin to break free and start rotating; the torque at that instant would be the value recorded. Thereafter, whenever the turntable was stationary during a test and the angular-position-control subsystem called for rotation, the friction-compensating control subsystem would command the friction-compensating motor to apply the break-free torque in the direction of commanded rotation.

In addition to compensating for friction, the turntable control system could command the simulation of a variety of dynamic effects, including those caused by friction in other equipment or longitudinal movement, on the turntable, of the equipment under test. The torque effects to be simulated could be introduced by use of appropriate torque-vs.-speed and/or torque-vs.-angular position algorithms in a computer in the torque-compensating control subsystem.

This work was done by Craig C. Sullender, Kevin R. McCarthy, and Bradley J. Suppanz of Rockwell International Corp. for **Lewis Research Center.** *For further information,* ***write in 83*** *on the TSP Request Card.* *LEW-15695*

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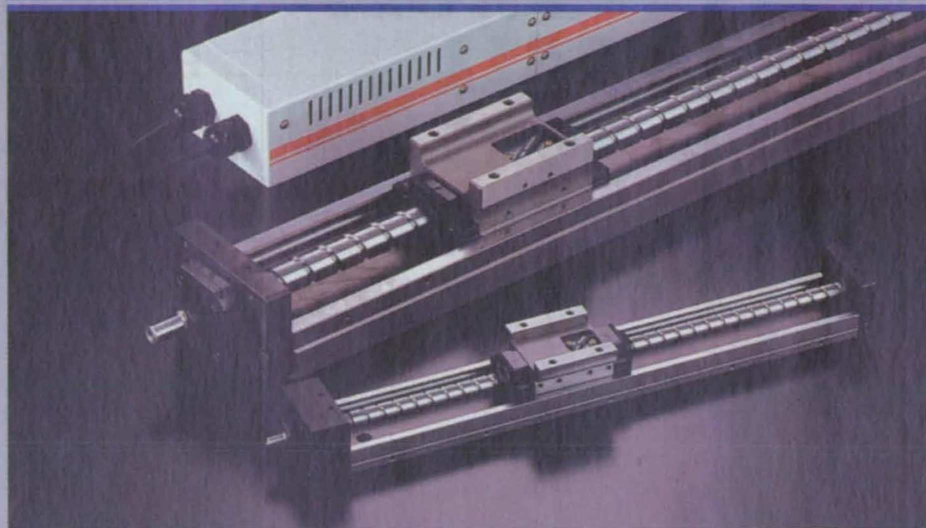

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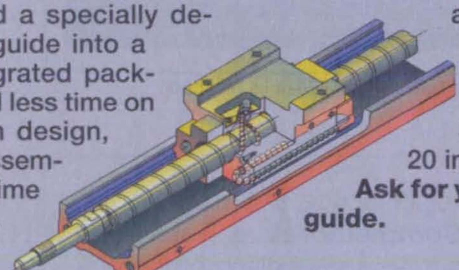

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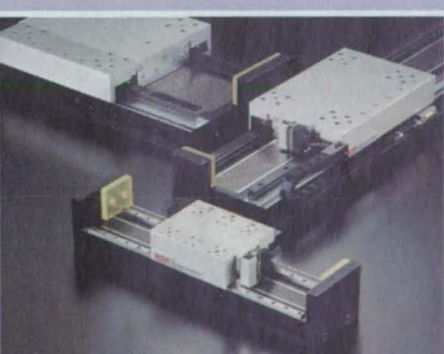

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Reduced-Weight, Reduced-Backlash Planetary Gearhead Stage

Other features include high torque capacity and an axial hole for cables.

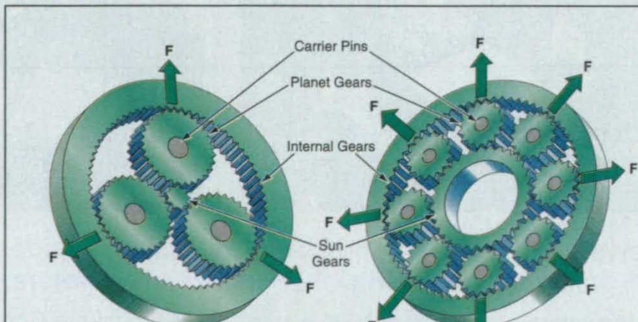
NASA's Jet Propulsion Laboratory, Pasadena, California

An improved planetary gearhead stage weighs less, produces less backlash, and has greater output torque capacity than does a conventional planetary gearhead stage of the same outside diameter. It also includes an axial through-hole that can be used as an open optical path or to accommodate wires, optical fibers, pneumatic or hydraulic tubes, mechanical actuator cables, and/or other connections. This planetary gearhead stage is prototypical of a class of high-torque output stages of compact, lightweight multistage gearheads that can be used in the joints of robot arms.

The figure illustrates some of the differences between this and a conventional planetary gearhead stage. The sun gear has been enlarged into a ring to accommodate the axial through-hole. The enlargement of the sun gear enables an increase in the number of planet gears from three to eight. One result of the increase in the number of planet gears is that each planet gear can share a smaller part of the load. Because there are more planet gears, there are also more pins to transmit the output torque, and the load per pin is reduced. Moreover, the pin-circle diameter is greater, so that the output torque capacity is increased.

Another result of the increase in the number of planet gears is that the outward radial forces of the planet gears on the internal gear are applied more nearly uniformly around the circumference, so that these forces tend to induce less deformation of the internal gear from its nominal circularity than they do when these forces are applied at only three points as in the conventional design. Thus the internal gear can be made thinner because less stiffness is needed to maintain circularity. If the internal gear has a thin wall and oversized planet gears are used, the internal gear can be stretched slightly over the planet gears to reduce or eliminate backlash.

The main disadvantage of the improved design concept is that the torque-increase and speed-reduction ratios are



The **Improved Planetary Gearhead Stage** contains more planet gears and a thinner, slightly conformable internal gear. The internal gear is fixed, the sun gear provides input torque, and torques contributed by the forces on the planet gears are transmitted to an output shaft via the carrier pins.

reduced. The ratio for a typical conventional planetary gearhead stage is about 5:1, whereas that of a stage according to the improved concept is typically about 3:1. Of course, this limitation can be overcome by use of multiple stages. Alternatively, if an axial hole through all stages of a multistage gearhead is not needed, then the improved design can be reserved for the final high-output-torque stage and the preceding stages can be of conventional design.

This work was done by Timothy R. Ohm of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 30*** *on the TSP Request Card. NPO-19321*

Tracking Motions of Manually Controlled Welding Torches

Positions, orientations, and velocities would be determined in real time during manual arc welding.

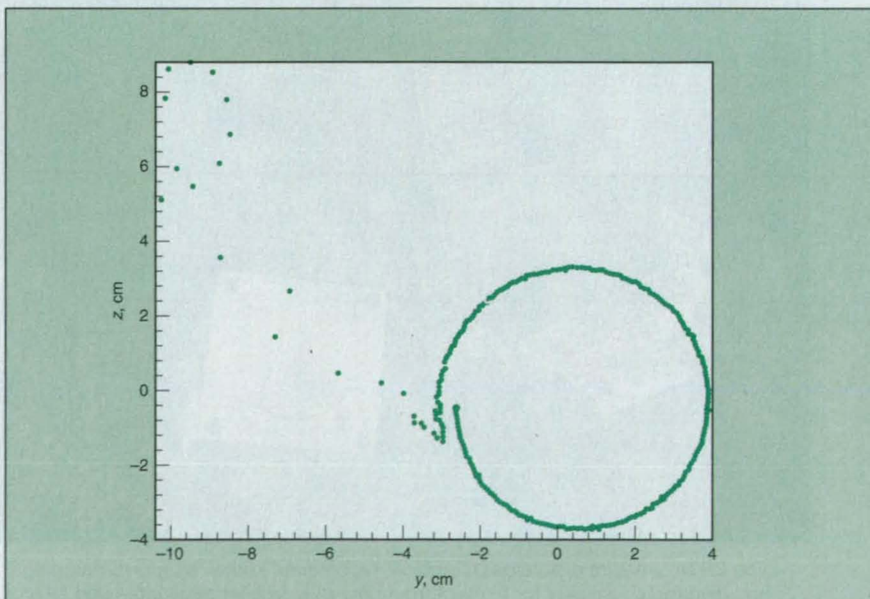
Marshall Space Flight Center, Alabama

Techniques for measuring the motions of manually controlled welding torches in real time are undergoing development. The purpose of this development is to make it possible to treat manual welding processes more systematically so that manual welds can be made more predictable, especially in cases in which the mechanical strengths and other properties of welded parts are highly sensitive to heat inputs and thus to velocities and orientations of welding torches.

As the concept is envisioned at the present early stage of development, the position and/or orientation of a welding torch could be measured by sensors such as accelerometers, gyroscopes, electrolytic tilt sensors, or mechanical linkage devices with encoders. In a proof-of-concept demonstration with no arc operating, an electromagnetic sensor was used to obtain six-degree-of-freedom data on position and orientation of a welding torch that was moved along various test trajectories. Software to process these data into usable form (see figure) and to compute the velocity of the tip of the torch was developed. Present work is being conducted under full welding conditions using a six-degree-of-freedom jointed arm to track torch motion.

This work was done by Carolyn Russell of **Marshall Space Flight Center** *and Ken Gangl of Advanced Welding Concepts, Inc. For further information,* ***write in 91*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-26330.



This **Trajectory Was Computed From Measurements** taken by an electromagnetic sensor as the welding torch was moved in a circular path about a fixed tube.

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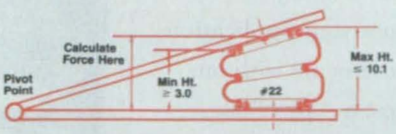

- **Tolerance to off-center & minor side loading**—Airstroke actuators are virtually unaffected by off-center & side loading, while conventional cylinders end up with bent rods, scoring and excessive seal wear. You save on replacement costs and downtime with Airstroke actuators.

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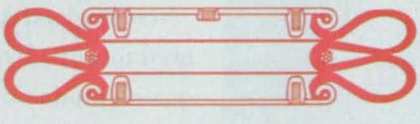

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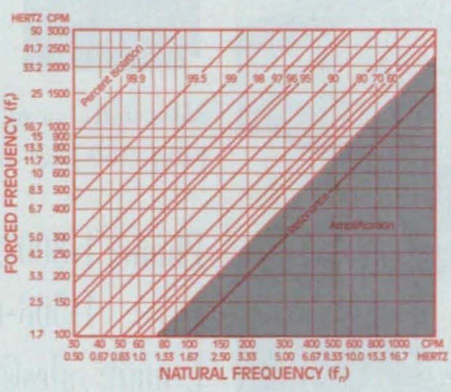
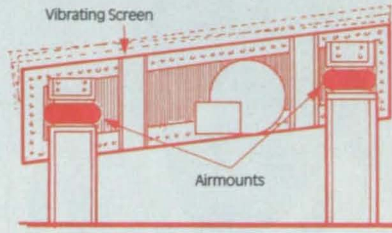
Outperforms other vibration isolators

For vibration isolation and shock bumpers or stops, Airmount isolators give you:

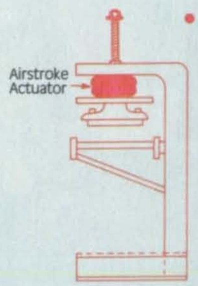
- **Unsurpassed isolation capability**—no coil spring isolates vibration like air can. System natural frequencies as low as 60 cycles per minute—1 HERTZ—can be achieved. A coil spring would have to provide a real deflection of 9" to compare.



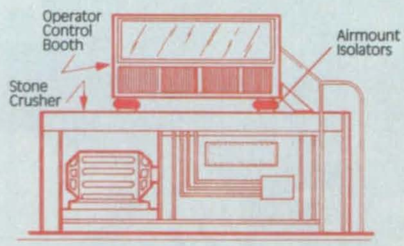
- **Constant isolation efficiency**—a unique feature that means the spring system frequency does not change with changes in load. The advantage to you is that one size Airmount isolator can be used at each mounting point of an unevenly loaded machine.



- **Effective noise reduction**—no "chatter" like metal coil springs. Rubber and air Airmount isolators are quiet in themselves. The result is a quieter work environment, along with better structural member protection.



- **Versatility**—Airmount isolators handle loads from 100 lbs. to 100,000 lbs. per mounting point. Installed height can be as low as 2.5", with accurate height control through internal air pressure regulation. Airmount isolators are as applicable on heavy vibrating machinery as they are on delicate, sensitive types of equipment.



Both Airstroke actuators and Airmount isolators come in a wide range of sizes to give you precise application fit. Firestone can make your motion and vibration problems disappear into thin air. Call your local distributor today for design assistance.

Firestone

World's Number 1 Air Spring.

FIRESTONE INDUSTRIAL PRODUCTS COMPANY

701 Congressional Blvd., Carmel, IN 46032 317/580-2300

For More Information Write In No. 804

Motion Control Industry Leaders

FIRESTONE INDUSTRIAL PRODUCTS COMPANY

Firestone is the manufacturer of the world's #1 air spring for both vehicular and industrial applications. Division headquarters and main sales offices are located in Carmel, IN, with manufacturing facilities in Noblesville, IN; Williamsburg, KY; Dyersburg, TN; and Sao Paolo, Brazil. Additional sales offices are located in Southfield, MI; Staines, Middlesex, England; and Sao Paolo, Brazil.

Firestone developed the air spring in the late 1930s as a more efficient spring (vibration isolator) for use in vehicle suspensions. Airide® springs, as they were named, provided the means for a suspension to reduce the amount of road shock and vibration transmitted into the vehicle. Millions of miles of actual use have proven the dependability and effectiveness of the air suspension concept using Airide® springs by Firestone.

In addition to their use on heavy-duty trucks, Firestone air springs are also used on passenger-rail cars, buses, light- and medium-duty trucks and buses, and automobiles.

In industrial applications, Airstroke® actuators are capable of generating a force of 100,000 lbs., and Airmount® isolators can isolate up to 80,000 lbs. They are available in a wide variety of sizes ranging from as small as 2.8" in diameter to 37".

Some of the industries that utilize air springs include: manufacturing, forest products, pulp and paper, aerospace, steel, packaging, material handling, amusement and entertainment, food processing, agriculture, transportation—or anywhere something needs to be moved, pushed, lifted, or isolated.

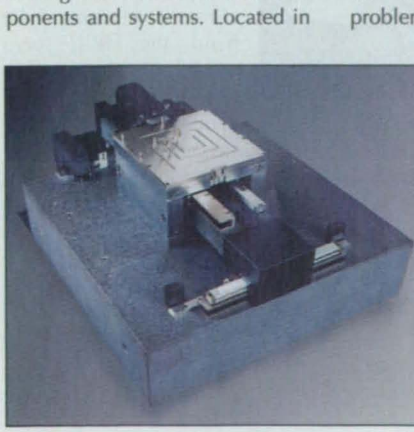
For more information, call 1-800-888-0650 or E-mail Firestone via the Internet: firestone@industry.net; England: 44-1784-462-326; Brazil: 55-11-411-1166.

For More Information Write In No. 811

NEW ENGLAND AFFILIATED TECHNOLOGIES

Motion Control and Positioning Systems and Components

New England Affiliated Technologies (NEAT) is a leading manufacturer of precision positioning and motion control components and systems. Located in Lawrence, Massachusetts, NEAT was established as a division of Instrument Industries, Inc. and has been solving positioning problems for over 20 years.



NEAT operates two, uniquely integrated facilities: a 33,000 square foot building houses the engineering, product design and development, assembly, machining, and administrative teams, while a 13,000 square foot building serves as a Large Systems Facility for the design and production of sizable positioning systems. These tightly integrated teams and facilities allow NEAT to minimize the design and build cycle and respond promptly to customer requirements.

NEAT employs engineers with experience in electronics, mechanics, optics, and physics. In many cases, positioning requirements, whether simple or complex, cannot be met with standard, off-the-shelf components. NEAT's special strength lies in their willingness and ability to provide solutions, not just components.

NEAT prides itself on supplying optimal solutions to challenging customer requirements in fields such as semiconductor inspection and probing, digital imaging, optical bonding, and general automation.

NEAT regularly designs and builds high vacuum positioning systems, such as the spectrometer positioners aboard ESA's SOHO satellite.

Contact: Krista Fabian, NEAT, 620 Essex Street, Lawrence, MA 01841; Tel: 1-800-227-1066; Fax: 1-800-523-8201.

For More Information Write In No. 812

NSK CORPORATION, PRECISION PRODUCTS DIVISION

NSK Corporation is a world-class manufacturer of precision motion control components and systems. Product offerings include high-precision direct drive rotary and linear motors, X-Y stages, high-speed indexers, ball screws and linear ball bearing guides. The Precision Products Division is a leading U.S. supplier of high-quality and high-accuracy mechanical and mechatronic components to many industries.

Precise positioning is achieved with both the direct drive YS Series MegaTorque® Motor System and linear Y Series MegaThrust Motor System. The MegaTorque rotary positioner is a direct drive DC brushless servo that provides high speed and extremely accurate positioning capabilities. Gearless design means zero-backlash, micron level positioning and maintenance-free operation. Permanently lubricated bearings can handle axial loads up to 4000 lbs. The system provides high reliability and comes in a variety of sizes and models including waterproof styles. Up to 360 ft./lb. of torque, speeds as high as 180 rpm and resolution of 2.1 arc/sec. It provides ideal motion control for robots, indexers, automatic assembly and machining applications.

The YS Series comes complete with interchangeable motor, programmable driver and cables. It is equipped with an RS-232C interface to make programming simple and convenient. A hand pendant is used to input parameters and programs for the first time or if the motor is not connected to a personal computer.

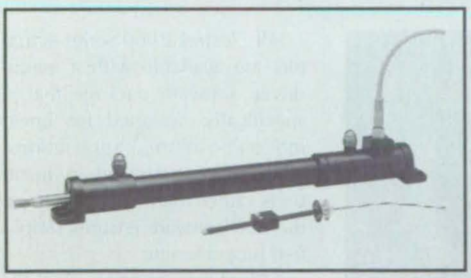
The MegaThrust Motor is a linear positioner that incorporates the same principles of the MegaTorque motor. Direct drive eliminates backlash and loss of accuracy common in mechanical designs. Standard, multi-function digital servo driver can be interfaced with a variety of remote components and controllers for sophisticated sequencing. Motor generates up to 132 lbs. of force with speeds up to 71 in./sec. with ±1 micron repeatability. Effective stroke lengths up to 100 ft.

For more information, contact NSK Corporation, Precision Products Division, 250 Covington Dr., Bloomingdale, IL 60108; Tel: 800-255-4773; Fax: 708-924-8197.

For More Information Write In No. 815

OILDYNE EMC GROUP

Introduces Two New Innovative Products



½" Bore Smart Cylinder

1/2" Bore Hydraulic Smart Cylinder

Oildyne EMC Group has designed one of the smallest Smart Cylinders ever available. The cylinder is a remarkably small 1/2" bore, complete with an internal position feedback transducer that provides for infinite positioning capability. This is a perfect package for those applications where space is a premium but positioning and hydraulic forces are required.

The cylinder features a maximum 9" stroke length and pressures up to 2500 psi. There is a miniature 3-pin quick disconnect electrical connector for connection to a PLC or other electronic motion controller.

Miniature Valve Pad Smart Cylinder

Oildyne has also developed a miniature Smart Cylinder featuring an integral hydraulic proportional valve pad and valve. Now, for the first time, it is possible to have a 1" bore hydraulic smart cylinder and mini hydraulic proportional valve as one complete integrated package. This provides a totally unique product for those applications where space is at a premium but hydraulic forces and positioning are a requirement.

These products are part of a uniquely designed linear resistor position transducer family that allows for internal installation in cylinders as small as 1/2" bore. They feature a right angle exit for an electrical connection that provides an advantage not found in most position transducers. The design also has the advantage of being manufactured in any length desired rather than only in 1", 2", or 6" increments. For hydraulic or pneumatic applications the LRT/MLRT family provides the designer the opportunity for the smallest profile, infinite resolution, and linearity from .1% to 1% of stroke, depending on the model.

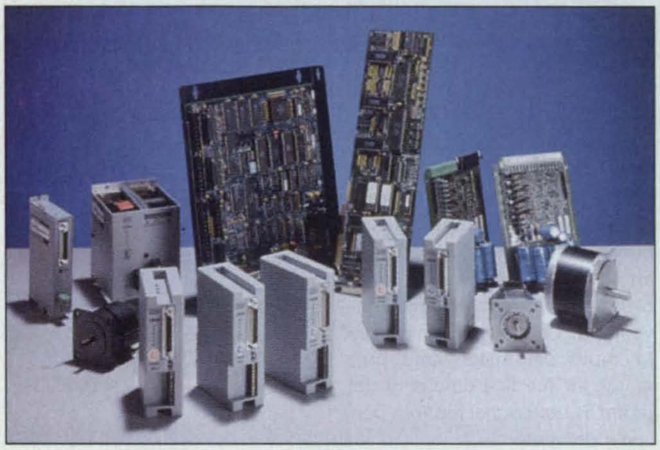
For More Information Write In No. 816

1" Bore with Mini NG3 Valve

PARKER HANNIFIN CORP., COMPUMOTOR DIVISION

Compumotor: A Pioneer in Microstepping and Servo Motor Technologies

Incorporated in 1979, Compumotor earned its reputation for innovation by pioneering microstepping drive techniques to improve the smoothness and resolution of step motor control systems. Compumotor's innovative leadership has continued to produce a complete line of stepper motor and servo drive systems, computer bus-based and stand-alone controllers, and extensive applications software. Parker Hannifin's acquisition of Compumotor in 1986 fostered breakthroughs in servo technology, followed by AC brushless drives, DSP servo controller techniques, and smart drive controller combinations. Today, after a decade of innovation, Compumotor is among the largest service-oriented and most technologically advanced suppliers of electronic motion controls in the world.



The Complete Solution

We provide more than just the products necessary for today's demanding automation requirements. An accessible network of knowledgeable worldwide support resources accompanies every product. To maintain our leadership position in the electronic motion control industry as a complete supplier of electromechanical solutions, it is mandatory that we continue to identify, invest in, and develop those technologies, products, services, and processes that will always keep our products ahead of the competition.

Custom Service and Custom Products

It is impossible to anticipate every need of every individual (and unique) customer. After evaluating our extensive line of products, you may decide that a customized version of a standard product is required. A custom product can be anything from a software modification to integrating our products into larger systems. Compumotor is prepared to quickly respond and adapt to your specific requirements.

The Right Choice

Compumotor's distinguished product excellence and experience in the electronic motion control industry is as far-reaching as our global support network. Selecting a Compumotor product is much more than a decision for today—it is an investment in your future.

For more information, write to: Parker Hannifin Corp., Compumotor Division, 5500 Business Park Drive, Rohnert Park, CA 94928.

For More Information Write In No. 817

WARNER ELECTRIC

Offers Programmable Linear Actuators

Warner Electric, long a leading supplier of linear and rotary motion control devices, now offers an extensive line of programmable linear actuators that features greater service life and expanded load-carrying capabilities, operating speeds, duty cycles, and accuracies. Named the *Electrak 2000*, this industry-leading line of linear actuators is available in both high-efficiency ball screw and economical Acme screw models.

All *Electrak 2000* actuators are engineered to operate for up to 50 million cycles. Operating speeds range from 20 inches/second for 40-lb. loads to 2 inches/second for 500-lb. loads, with repeatability of 0.0005 inches. Standard stroke lengths are 2, 4, 6, 8, 12, 18, and 24 inches. The maximum load capacity for parallel models with ball screw drive is 2000 lbs.

Ball screw models feature excellent speed, load, and duty-cycle capabilities with low power consumption. An electrically-released, spring-set brake mounted on the step motor controls back-driving of the ball screw actuator if power is interrupted.

Acme screw units offer an economical alternative for applications with lower load, speed, and duty-cycle requirements. The Acme screw models can hold vertical loads without back-driving in either a power-off or a stall mode.

Designed to be impervious to washdowns, *Electrak 2000* sealed step motors carry an IP-56 rating and are featured as standard equipment. Controls are supplied complete with I/O boards, input power cables, indexer, and drive.

All *Electrak 2000* Series actuators are available with a menu-driven software package that is specifically designed for linear motion/position applications. With terms expressed in linear units rather than in motor steps, the new software ensures simplified programming.

Mounting options include front flanges, trunnions, side-tapped holes, and mounting feet. Encoders, sensors, and brakes are offered as options. Both parallel and in-line actuator configurations are available.

For additional technical information on any Warner Electric product, contact: Warner Electric Advertising Department, 449 Gardner Street, South Beloit, IL 61080; Tel: 815-389-3771; Fax: 815-389-2582.

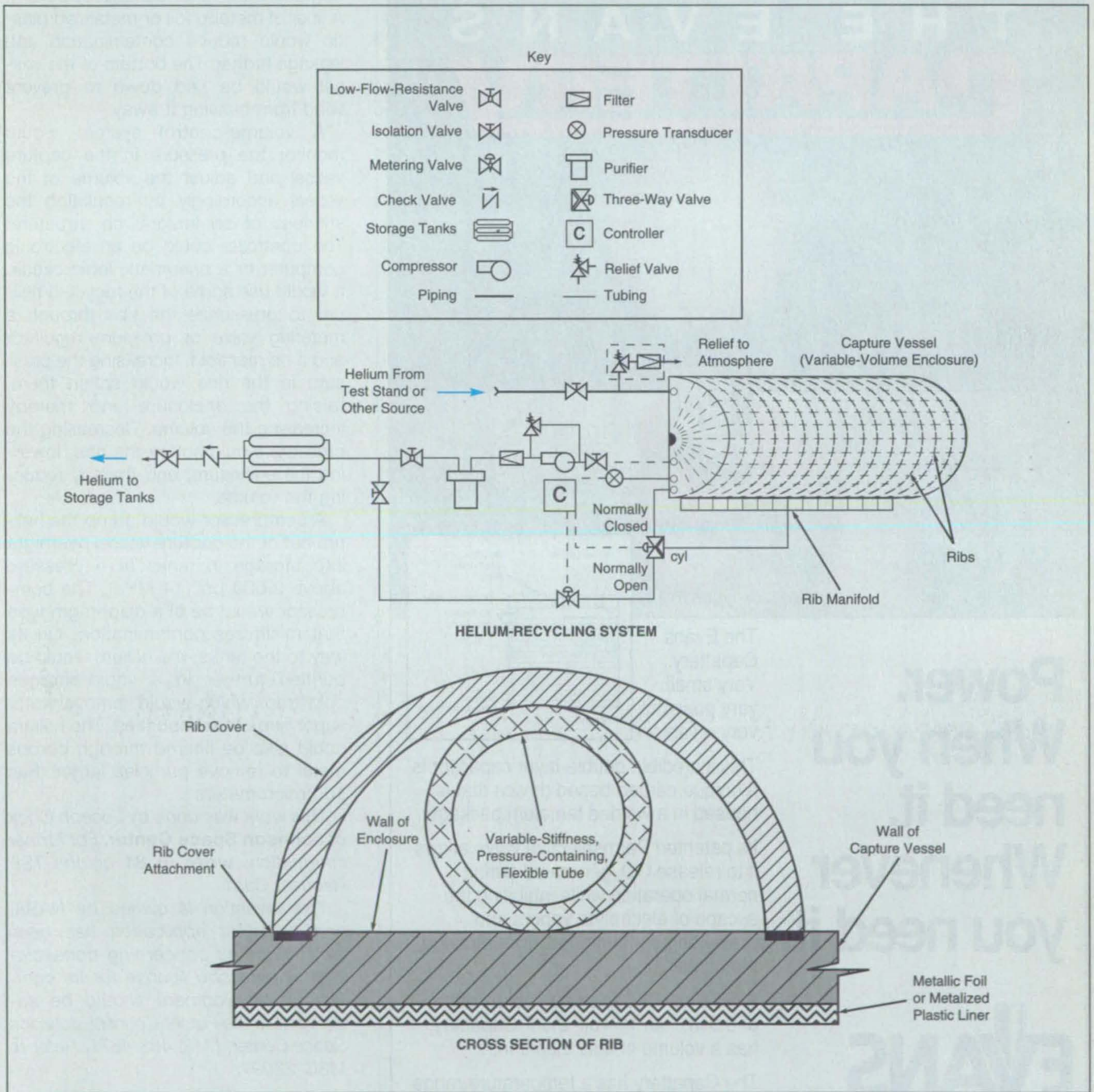
For More Information Write In No. 818

Helium-Recycling Plant

Helium would be conserved with little contamination or back pressure on the source.

Lyndon B. Johnson Space Center, Houston, Texas

A proposed system would recover and store helium gas for reuse. The system would maintain the helium at 99.99-percent purity, preventing water vapor from the atmosphere or lubricating oil from pumps from contaminating the gas. The system would take in the gas at a nearly constant low back pressure near atmospheric pres-



Helium From a Test Stand would enter a variable-volume capture vessel for temporary storage before being transferred to tanks for longer-term storage. The capture vessel would be a buffer that would prevent the application of excessive back pressure to the test stand.

sure [14.7 psi (0.101 MPa)]; that is, it would introduce little or no back pressure into the source of helium.

The helium-recycling system was conceived for test facilities of NASA and its contractors, which together use almost 10 million standard cubic feet (about 283,000 standard cubic meters) of helium per year. Recycling would save an estimated $650,000 (in 1992 prices) annually. The concept could also be extended to recycling of other gases. The helium to be recycled would enter the system through inlet pipes that would route the helium from a test stand or other source to a semicylindrical capture vessel (see figure). The pipes, typically 3 in. (7.6 cm) in diameter, would be designed to offer low resistance to flow and, consequently, low pressure drop. The inlet plumbing would include a butterfly-type isolation valve and a filtering relief valve, which would keep out particulate contamination while preventing excessive buildup of pressure in the vessel.

The capture vessel would be a lined variable-volume enclosure that would be made to expand to accommodate the incoming helium. The growth of the capture vessel during intake of helium would prevent the buildup of back pressure that would interfere with the operation of the source of helium. The maximum expansion of the vessel would accommodate 60,000 ft^3 (about 1,700 m^3) of helium — the amount emitted by a full day's operation of the test stand for which the system was conceived.

The walls of the capture vessel would be made of a low-outgassing material that would have a low permeability by helium, so as to minimize contamination and leakage of helium. A liner of metallic foil or metalized plastic would reduce contamination and leakage further. The bottom of the vessel would be tied down to prevent wind from blowing it away.

A volume-control system would monitor the pressure in the capture vessel and adjust the volume of the vessel accordingly by regulating the stiffness of an integral rib structure. The controller could be an electronic computer or a pneumatic logic circuit. It would use some of the recycled helium to pressurize the ribs through a metering valve or pressure regulator and a rib manifold. Increasing the pressure in the ribs would stiffen them, raising the enclosure and thereby increasing the volume. Decreasing the pressure would soften the ribs, lowering the enclosure, and thereby reducing the volume.

A compressor would pump the helium out of the capture vessel overnight into storage in tanks at a pressure above 2,000 psi (14 MPa). The compressor would be of a diaphragm type that minimizes contamination. On its way to the tanks, the helium would be purified further in a liquid-nitrogen cold trap, which would remove water vapor and other impurities. The helium could also be filtered through porous metal to remove particles larger than 100 micrometers.

This work was done by Joseph Cook of **Johnson Space Center.** *For further information,* ***write in 81*** *on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center; (713) 483-4871. Refer to MSC-22091.

Noncavitating Pump for Liquid Helium

An immersion pump features high efficiency in cryogenic service.

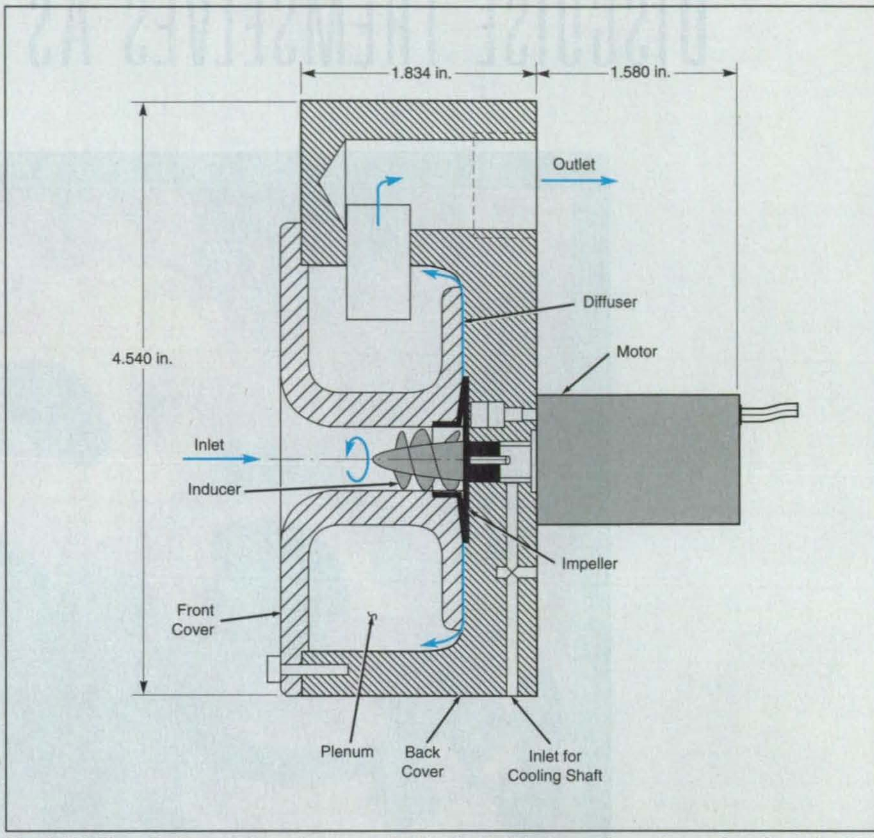
Ames Research Center, Moffett Field, California

A simple and reliable centrifugal pump transfers liquid helium with a mass-transfer efficiency of 99 percent — no more than 1 percent of the cryogenic liquid is lost by boiling off due to energy input from the pump. The pump operates without cavitation even with negative values of net positive suction head. (Net positive suction head is the difference in static head between the liquid at the inlet of the pump and the static head in saturated vapor.)

The purpose of the pump is to transfer liquid helium from a supply to a receiver vessel, or to provide liquid helium flow for testing and experimentation. The pump includes an induction motor, a centrifugal impeller, a helical inducer, solid-lubricated ball bearings, and a housing (see figure). It is located in a supply vessel submerged in liquid helium, which also serves to cool the motor. With a net positive suction head of −12 cm or more, the pump delivers 800 L/h at a head of 128 J/kg and an impeller speed of 12,000 r/min.

Liquid helium first flows into the inducer, then flows into the centrifugal impeller. The inducer resists blockage of flow from cavitation and imparts a small head to the inlet stream to reduce the tendency to cavitation in the impeller. The centrifugal force in the impeller provides most of the pressure rise through the pump. The liquid helium flows radially away from the impeller through the diffuser region between front and back covers, then enters a plenum that surrounds the inlet. As the helium decelerates in the diffuser and plenum, its kinetic energy is partially converted into increased pressure. From the plenum, the liquid leaves the pump through the outlet port.

There are two ball bearings, that carry axial and radial shaft loads. The bearings consist of stainless-steel balls and raceways with fiberglass/polytetrafluoroethylene/nylon composite retainers, selected for a combination of durability and lubricating properties in a severe cryogenic environment. After 24 h of continuous operation, the bearings showed light wear but no sign of imminent failure.



Liquid Helium Is Drawn into the pump by the helical inducer, the primary function of which is to pressurize the helium slightly to prevent cavitation when the liquid enters the impeller. The impeller then pressurizes the liquid.

The motor is of a three-phase ac, squirrel-cage type. An induction motor was chosen for its simplicity and absence of commutating electrical connections (graphite brushes in commutators are short-lived in a dry environment with no moisture for lubrication).

This work was done by Robert Hasenbein, Michael Izenson, Walter Swift, and Herbert Sixsmith of Creare, Inc., for **Ames Research Center.** *For further information,* ***write in 56*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center; (415) 604-5104. Refer to ARC-13229.

Magnetostrictive Actuators for Cryogenic Applications

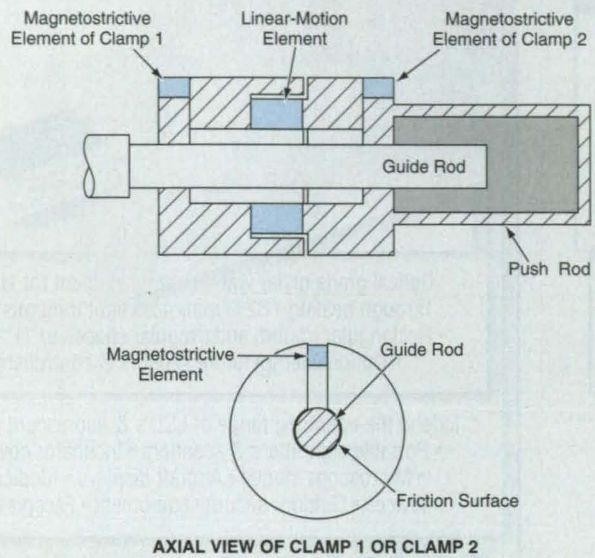
These actuators would work at both room and cryogenic temperatures.

NASA's Jet Propulsion Laboratory, Pasadena, California

Linear-translation motors containing magnetostrictive actuator elements have been proposed for use in making fine position adjustments on scientific instruments at temperatures from near absolute zero to room temperature. Like piezoelectric actuators of a similar type described previously in *NASA Tech Briefs*, these actuators would produce small increments of linear motion and would operate in a "set-and-forget" mode in the sense that they would automatically lock themselves against motion when power was not applied. Conversely, they would not consume or dissipate power when stationary.

The reason for using magnetostrictive (as distinguished from piezoelectric)

actuators is that magnetostrictive actuators function throughout the desired temperature range, whereas piezoelectric actuators tend to become inoperable in cryogenic environments. Although voice-coil actuators have been demonstrated at low temperatures, they cause waste of cryogen (because of continued consumption and dissipation of power when stationary at nonequilibrium positions), offer limited maximum displacements, and require complicated controllers. Because of the "set-and-forget" mode, the proposed actuators would thus offer advantages over voice-coil actuators; namely, less power dissipation (and consequently less consumption of cryogen). The proposed linear-translation motors could also be made to produce large maximum displacements.



When this **Linear-Translation Motor** was not powered, friction created between the clamps and the guide rod would maintain the position of the motor along the guide rod. The motor would move in steps; during each step, a motor controller would systematically turn the power on and off in the magnetostrictive elements.

Moreover, the controller of a motor of the proposed type could be relatively simple because it would be required to generate only simple sequences of on/off commands for three magnetostrictive actuator elements. As shown in the figure, these elements would be (1) a magnetostrictive element that, when energized, would pry clamp 1 open just enough to allow clamp 1 to slide on the guide rod; (2) a similar element in clamp 2; and (3) a linear-motion element.

One cycle of operation (during which the motor would effect one increment of linear motion) would consist of the following events:

1. Friction in the clamps would maintain the initial position as long as power was not applied.
2. Power would be applied to the magnetostrictive element in clamp 1, causing this clamp to release the guide rod while clamp 2 continued to grip.
3. The linear-motion element would be energized, causing clamp 1 to translate one increment of position, relative to clamp 2, along the guide rod.
4. Power would be removed from the magnetostrictive element in clamp 1, causing clamp 1 to grip the rod. Thus, at this point, both clamps would grip the rod.
5. Power would be applied to the magnetostrictive element in clamp 2, causing this clamp to release the guide rod while clamp 1 continued to grip.
6. Power would be removed from the linear-motion element, causing clamp 2 to move along the guide rod by the same amount and in the same direction as clamp 1 moved previously.
7. Power would be removed from clamp 2, so that both clamps would grip the rod.
8. At this point, the motor would be unpowered at the incremented position, and friction between the clamps and the guide rod would maintain the position as long as power was not applied.

This work was done by Benjamin P. Dolgin of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 67*** *on the TSP Request Card. NPO-19218*

Manufacturing Superconducting Cables

For protection, superconducting ceramic would be encapsulated before activation.

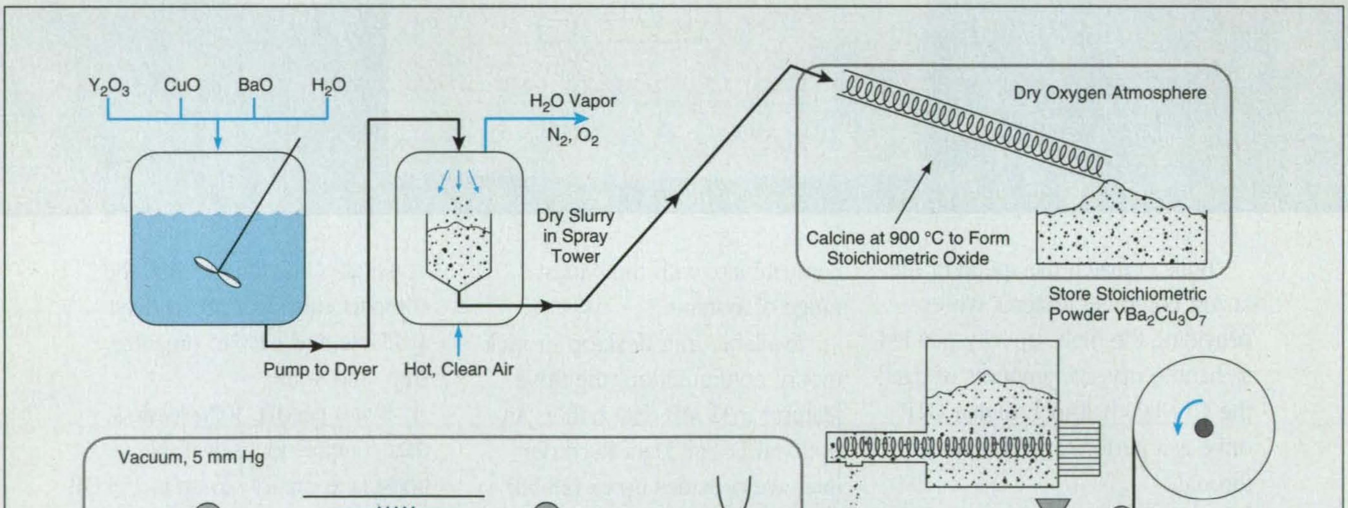
NASA's Jet Propulsion Laboratory, Pasadena, California

A process has been proposed for the manufacture of cables that contain the ceramic high-temperature-superconductor $YBa_2Cu_3O_{7-\alpha}$. The cables would carry electrical current with little or no loss of power when cooled to or below temperatures of about −200 °C. The process would accommodate the brittle nature of $YBa_2Cu_3O_{7-\alpha}$ and would be economical and readily controllable. It would also be flexible in the sense that it could be modified to accommodate a variety of precursor materials to be processed into $YBa_2Cu_3O_{7-\alpha}$.

The process (see figure) would begin with mixing of oxides of yttrium, barium, and copper with water to form a slurry, followed by drying of the slurry, followed by calcining in a rotating kiln to obtain a stoichiometric precursor powder oxide, $YBa_2Cu_3O_7$. The precursor powder would then be cooled, stored, and inspected for quality. A dry oxygen atmosphere would be provided during calcining, cooling, storage, and inspection to protect the precursor powder from water and other atmospheric contaminants.

In the next few steps, a thin metal foil would be unspooled and formed into a V-channel, into which the precursor powder would be metered. The foil is required to be permeable by oxygen at the high temperature (850 to 950 °C) to which the cable would subsequently be exposed (to activate the superconductivity as explained below), but to be impervious to oxygen and other environmental contaminants at lower temperatures at which the cable would be used. Vanadium has been tentatively selected as the foil material because it exhibits the desired permeability-versus-temperature characteristic, plus a favorable thermal-expansion characteristic. Niobium and tantalum may be suitable alternatives as foil materials. The foil would be continuously folded over and welded to seal the powder inside. The filling, folding, sealing, and most of the following operations would be performed in a vacuum to prevent trapping of gaseous oxygen in the cable. The cable would then undergo several steps of consolidation by rolling and heating, and the heating in these steps would also constitute preheating for the following activation step.

Activation of superconductivity would involve a controlled combination of (1) heating the precursor stoichiometric



A **Cable Containing Superconducting Ceramic** sheathed in metal would be drawn in a continuous process. The ceramic would be converted to a high-temperature superconductor after it had been encapsulated in metal foil.

$YBa_2Cu_3O_7$ powder to the activation temperature and (2) removing a small amount of oxygen to obtain the desired superconducting ceramic that is slightly substoichiometric in oxygen; namely, $YBa_2Cu_3O_{7-\alpha}$ (where α represents the deviation from stoichiometry). For this purpose, the cable would be pulled through a bath of molten lithium at the upper activation temperature of 950 °C. The affinity of lithium for oxygen would create a thermodynamic gradient of oxygen activity across the encapsulating foil, causing oxygen to diffuse out of the cable. Liquid sodium or liquid potassium might be used instead of liquid lithium, but their vapor pressures are higher — a disadvantage in the vacuum environment. The speed of the cable through the activation bath could be adjusted to adjust the immersion time and thus the amount of oxygen removed.

After emerging from the activation bath, the activated cable would be slowly cooled to room temperature, then brought out of the vacuum, then optionally clad with copper, which would provide additional support and protection and would serve, along with the foil, as an alternative path for current if the superconductor should fail. Finally, the cable would be wound on a spool for shipment.

This work was done by Christopher England of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 43*** *on the TSP Request Card. NPO-19196*

Compressor Case Made With Filaments Wound With V-CAP Resin

Weights and costs could be reduced.

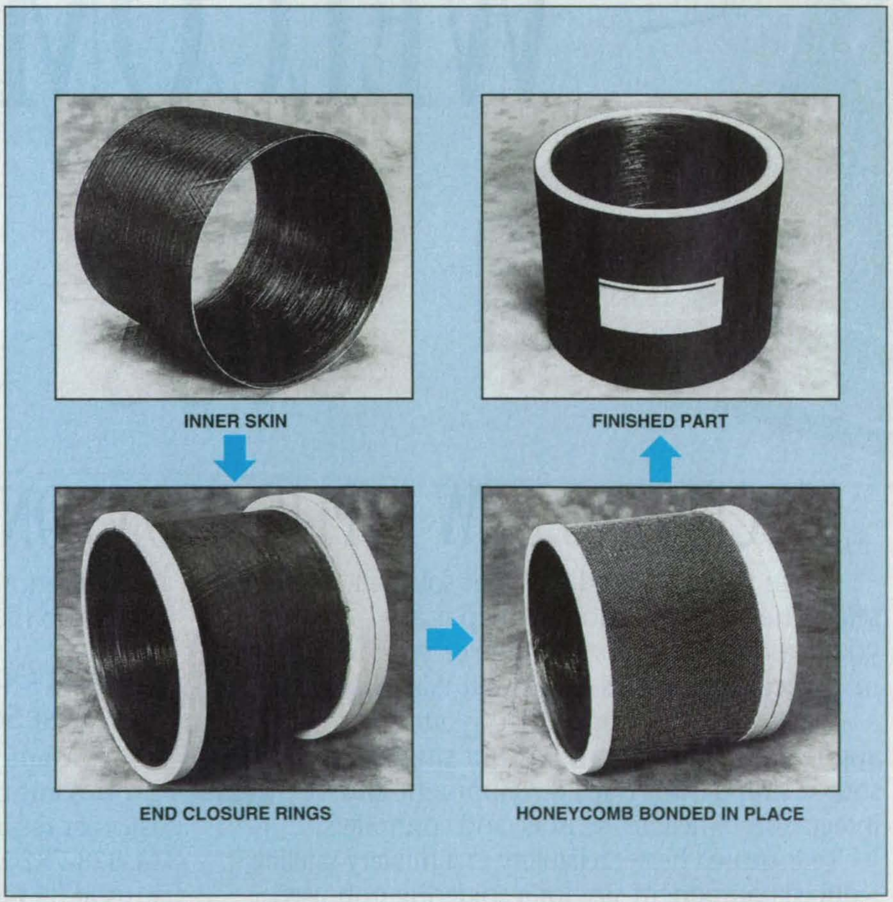
Lewis Research Center, Cleveland, Ohio

A laminated cylindrical composite-material compressor case has been fabricated in a process that includes winding of filaments wetted with matrix resins. This case is a prototype of lightweight composite compressor cases that are required to withstand internal temperatures as high as 700 °F (371 °C). These composite cases are candidates for replacing titanium compressor cases in high-temperature turbines: it has been estimated that in comparison with titanium compressor cases, the composite compressor cases could weigh about 30 percent less and cost about 10 percent less.

The figure shows the prototype case as a workpiece at various stages of fabrication. The case includes a two-layer inner skin, which was formed by winding filaments wetted with VCAP-75 polyimide resin onto a cylindrical mandrel. The filaments in the innermost layer were made of glass and were wound in a hoop configuration; the filaments in the adjacent layer were made of graphite and were wound in three sublayers in hoop, helical, and hoop configurations, respectively. The layers and sublayers were cured by heating, along with a combination of externally applied pressure and internal vacuum to remove bubbles.

The cured inner skin was trimmed to length and removed from the mandrel, at which point it was in the form of a thin-walled, self-supporting cylinder. Its outer surface was grit-blasted to roughen it to enhance adhesion of the following layers. Premolded closure rings made of phenolic resin, chopped glass, and microballoon filler were installed on the ends of the cylindrical inner skin and bonded in place by use of a high-temperature adhesive in bonding grooves. Next, a film adhesive was installed on all bonding surfaces and a premachined aromatic polyamide honeycomb layer was laid up onto the cylindrical inner skin. The honeycomb core was wrapped with shrink tape and the film adhesive was then cured.

The workpiece was reinstalled on the mandrel, more film adhesive was applied, and an outer layer of graphite filaments wetted with a high-temperature epoxy was wound onto the outer surface of the honeycomb core in sublayers with hoop and helical configurations. The epoxy was then cured, then the work-



The **Composite Compressor Case** is fabricated in stages that include winding of filaments wetted with matrix resins, adhesive bonding, layup, and several intermediate curing steps.

piece was trimmed to length and removed from the mandrel in its final form.

This work was done by Raymond Vannucci and James Sutter of **Lewis Research Center**; *W. Donald Humphrey, A. John Ayorinde, and Jeremy Eaton of Brunswick Composites, Inc. (Lincoln Composites); Ted Westerman of Allied Signal Engines; and Ron Allred of Adherent Technologies. No further documentation is available. LEW-15990*

Brazing Dissimilar Metals

Metals with widely different coefficients of thermal expansion can be joined.

Marshall Space Flight Center, Alabama

Brazing has been found to be an effective technique for joining ordinary structural metals to brittle, low-thermal-expansion refractory metals. Specifically, a brazing process has been established for (a) joining copper or nickel flanges to the ends of vacuum-plasma-sprayed tungsten tubes and for (b) joining stainless-steel flanges to the ends of tubes made of an alloy of molybdenum with 40 percent of rhenium.

In the original application, the tubes were furnace-cartridge tubes 23.5 in. (59.7 cm) long and 1 in. (25.4 mm) in diameter, with wall thickness of 0.030 in. (0.76 mm). The tubes were of test-tube configuration and the flanges were joined to the open ends.

In preparation for brazing, the tubes were cleaned of surface contaminants by placing them in a hydrogen furnace in the temperature range of 2,000 to 2,100 °F (approximately 1,100 to 1,150 °C) for 15 minutes. That area on each tube that was to be joined to a flange was then pre- "tinned" by wrapping the area with a thin brazing foil and heating it to the melting temperature.

After pretinning, each flange was machined to provide a braze-joint gap of 0.003 to 0.004 in. (0.076 to 0.10 mm). Each tube was then put together with its flange, and a small amount of brazing alloy was placed at the opening of the braze joint to provide sufficient material to fill the gap. A braze-stop-off solution was applied to the surfaces surrounding the joint to prevent the brazing alloy from flowing onto these surfaces and thereby make it unnecessary to perform a post-braze cleanup. The tubes were then brazed, variously, in an inert or vacuum environment in the vertical orientation with the flanges at the lower ends.

This work was done by Phillip D. Krotz, William M. Davis, and Daniel L. Wisner of Rockwell International Corp. for **Marshall Space Flight Center.** *For further information,* ***write in 12*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-30105.

Mathematical Model of Variable-Polarity Plasma Arc Welding

Marshall Space Flight Center, Alabama

A mathematical model of the variable-polarity plasma arc (VPPA) welding process has been developed for use in predicting the characteristics of welds and thus serving as a guide for the selection of process parameters. These parameters include the welding electric currents in, and the durations of, straight and reverse polarities; the rates of flow of plasma and shielding gases; and the sizes and relative positions of the welding electrode, the welding orifice, and the workpiece. The model includes submodels that approximate the time-dependent major electrical, thermal, radiative, and mechanical phenomena involved in the transfer of energy through the electrode and gases to the workpiece and environment. The model predicts (1) electric potentials (in both straight and reversed polarities) at key locations; (2) electric power input at the electrode, within the orifice, in the free plasma jet column, and in the weld keyhole in the workpiece; (3) power loss at the electrode, within the orifice but outside the electrode, in the standoff column, and in the workpiece; (4) enthalpy of the plasma arc; and (5) widths and heights of the crown and root of the weld bead. In a study, predictions by this model were found to agree fairly well with data on both normal and abnormal experimental welds.

This work was done by R. J. Hung of the University of Alabama in Huntsville for **Marshall Space Flight Center.** *For further information,* ***write in 57*** *on the TSP Request Card. MFS-26311*

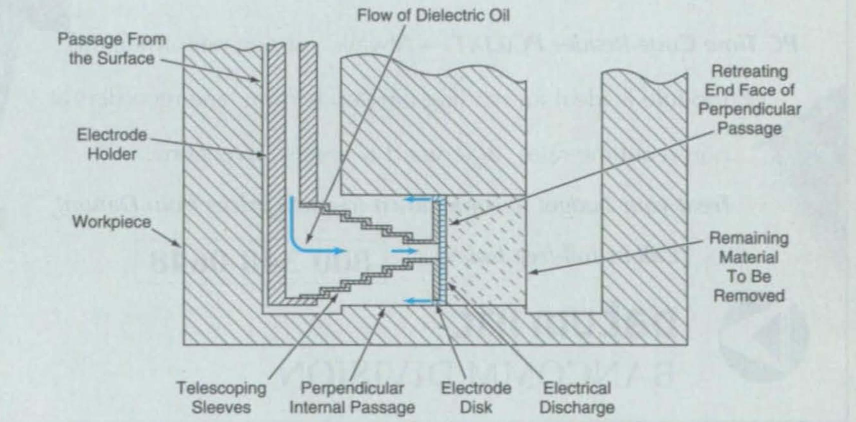
Electrical-Discharge Machining of Perpendicular Passages

A perpendicular telescoping electrode reaches into previously inaccessible places.

Marshall Space Flight Center, Alabama

A perpendicular telescoping electrode is used to perform electrical-discharge machining (EDM) of an internal passage through the previously inaccessible depth of a metal workpiece. More specifically, it is used to make an internal passage perpendicular to a passage that enters from the outer surface. Heretofore, the only way to make such a perpendicular internal passage was to make an access hole, then machine through the depth of material to form the passage, then restore the overlying material by welding a plug or other appropriately dimensioned piece of metal over the access hole.

The telescoping electrode is mounted on the lower end of an EDM electrode holder that is lowered into the passage from the surface (see figure). The telescoping electrode consists of an electrode disk supported on the narrowest one of a series of progressively narrower thin-walled copper sleeves. Attached to the smallest sleeve is an electrode disk the same diameter as the largest sleeve. The disk is the actual burning area. The sleeves are assembled concentrically and are compressed axially before lowering the electrode into the passage from the surface.



The **Telescoping Electrode** is extended into the perpendicular passage by the pressure exerted by the flowing dielectric oil.

The telescoping electrode is positioned at the depth of the perpendicular passage to be machined and its axis is aligned with the axis of the perpendicular passage. The electrode holder is hollow and is used as a manifold to supply dielectric oil to the electrode. The pressure exerted by the oil flowing through the electrode pushes the sleeves outward, thus extending the electrode so that the burning surface of the electrode disk follows the retreating end face of the passage. After the EDM is complete, the electrode can be retracted by use of a vacuum or compressed air.

This work was done by R. Michael Malinzak and Gary N. Booth of Rockwell International Corp. for **Marshall Space Flight Center.** *For further information,* ***write in 55*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-30027.

Verifying Removal of Red Penetrant Dye From Inspected Welds

A clean surface is assured for more sensitive inspection with fluorescent penetrant dye.

Marshall Space Flight Center, Alabama

A simple procedure has been devised to ensure that visible (red) penetrant dye that has been used to identify flaws in a welded surface has been completely removed from the surface. It is necessary to ensure complete removal because any residual red dye could interfere with a subsequent inspection in which ultraviolet illumination and a fluorescent penetrant dye are used to identify smaller defects.

The procedure consists in applying a reversible penetrant developer to the surface to be inspected. The developer contains a fluorescent dye that reacts with, and thus is eliminated by, the red penetrant dye. Therefore, when the surface is viewed under ultraviolet illumination, the residual spots of red penetrant dye stand out as dark spots against a fluorescent background. Once the removal of red penetrant dye has been completed and verified by this procedure, the developer is removed from the surface by rinsing with water.

This work was done by Jan R. Torkelson of Rockwell International Corp. for **Marshall Space Flight Center.** *For further information,* ***write in 76*** *on the TSP Request Card.*
MFS-30001

Mathematics and Information Sciences

Modified Mean-Pyramid Coding Scheme

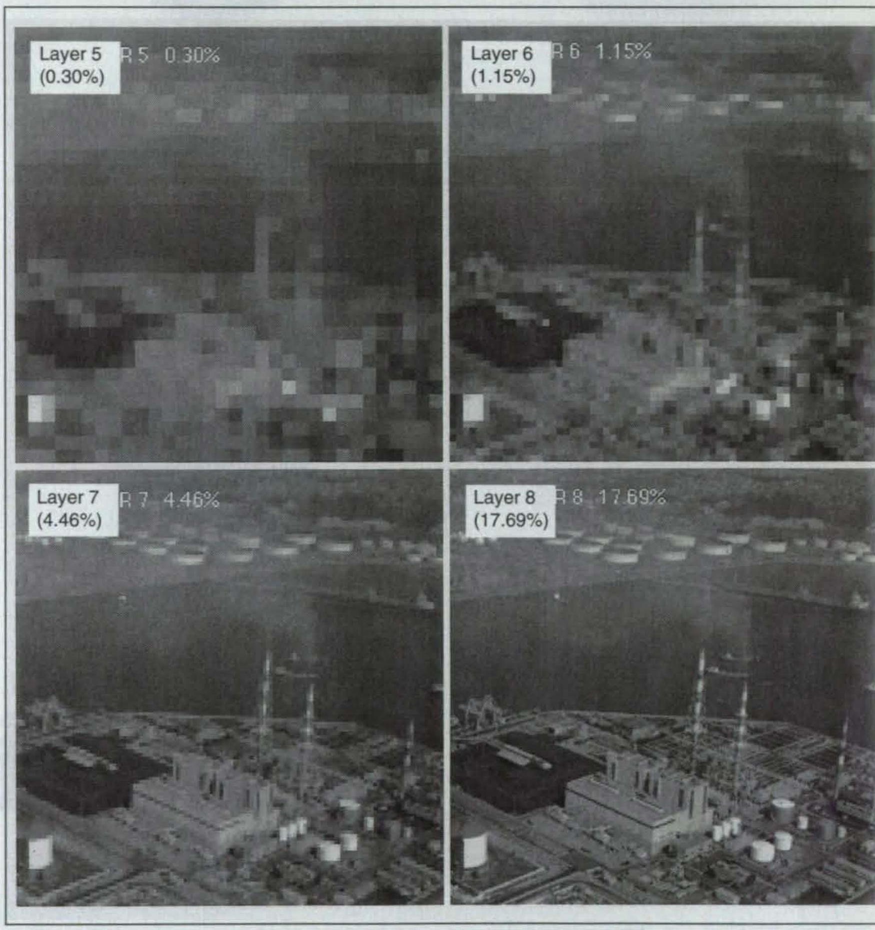
The data-expansion factor can be reduced from 1/3 to 1/12.

NASA's Jet Propulsion Laboratory, Pasadena, California

A modified mean-pyramid coding scheme requires the transmission of slightly fewer data than does the unmodified mean-pyramid coding scheme. These are schemes for the progressive transmission of image data. In progressive transmission (which should not be confused with "progressive scanning"), data on the entire image area are transmitted in a sequence of frames in such a way that a coarse version of the image can be reconstructed after the receipt of the first frame and an increasingly refined version of the image can be reconstructed after the receipt of each subsequent frame.

Progressive transmission offers an advantage when the time and/or the bandwidth available for transmission of image data is limited. When using a traditional line-by-line or raster scan, it is usually necessary to transmit the entire image before the user at the receiving end can recognize it. In progressive transmission, the user can view the increasingly refined approximate received images and make a decision as to whether it is worthwhile to continue refining the image or to devote the limited communication channel to another purpose — possibly the transmission of another image. In the mean-pyramid coding schemes, progressive transmission is combined with data-compression coding to decrease the bandwidth of the data signal, thereby further increasing the efficiency of utilization of the communication channel.

In the unmodified mean-pyramid coding scheme, the image data are represented by a hierarchical structure, which, in its simplest form, involves the construction of each succeeding higher and coarser layer by averaging over blocks of pixels (typically 2 × 2) in the layer immediately below it. The highest layer (which represents the average pixel intensity of the entire image) is transmitted first, followed by the differences between the highest and second highest layers, followed in turn by the differences between the third and second layers, and so forth. The differences between adjacent layers tend to be smaller more often than they are larger and can, therefore, be encoded with fewer bits (that is, compressed). The receiver decodes the transmitted data and partly mimics the operation of the transmitter in reconstructing approximate images of successively finer resolution.



A **Recognizable Image** is formed after fewer than 5 percent of the image data have been transmitted, and an image of fairly high quality can be reconstructed with fewer than 20 percent of the data.

The unmodified mean-pyramid scheme partly counteracts the effort to compress data in that it increases the number of data to be transmitted for each layer. In the case of an 8-bit gray-scale image of 512 × 512 pixels, the increase is by a factor of 1/3. The modification is directed toward reducing this expansion, and it involves the reconstruction of the fourth pixel in each block from (a) the three other pixels in the block and (b) the mean pixel in the next higher layer. In the absence of any further correction, this technique of reconstruction could introduce a truncation error into the fourth pixel, inasmuch as the mean pixel is the truncated average of the 2 × 2 block.

The truncation error is either 0, 1, 2, or 3 levels and is quite evenly distributed. The needed correction is supplied by transmitting the error term, which can be coded with 2 bits instead of the full 8 bits. This correction and representation guarantees lossless transmission and reduces the data-expansion factor from 1/3 to 1/12. The modified mean-pyra-

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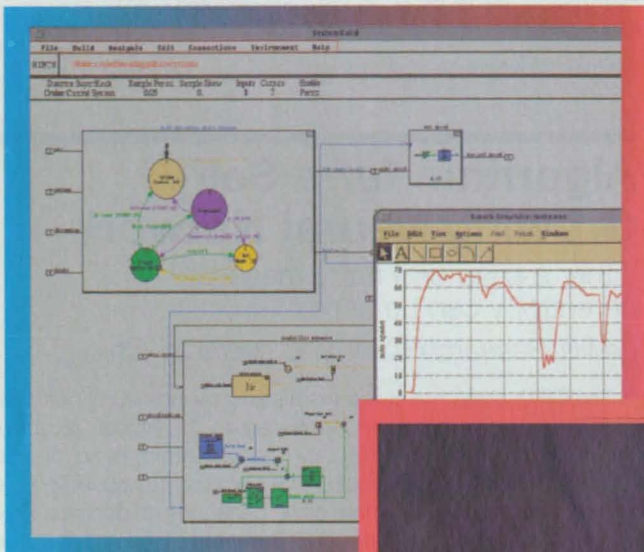

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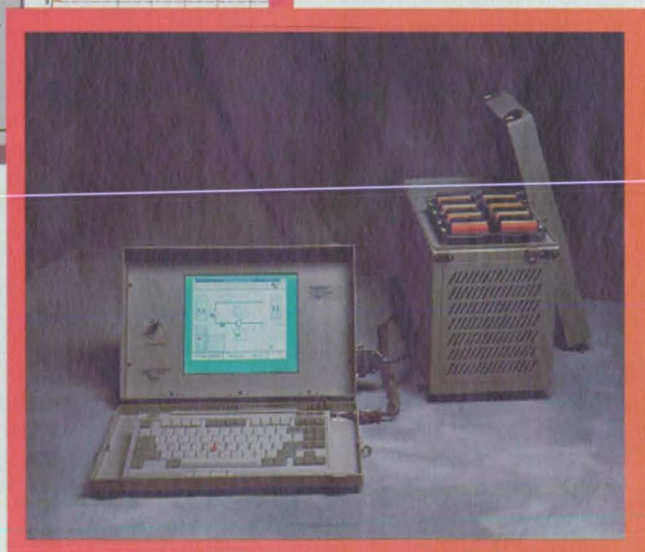

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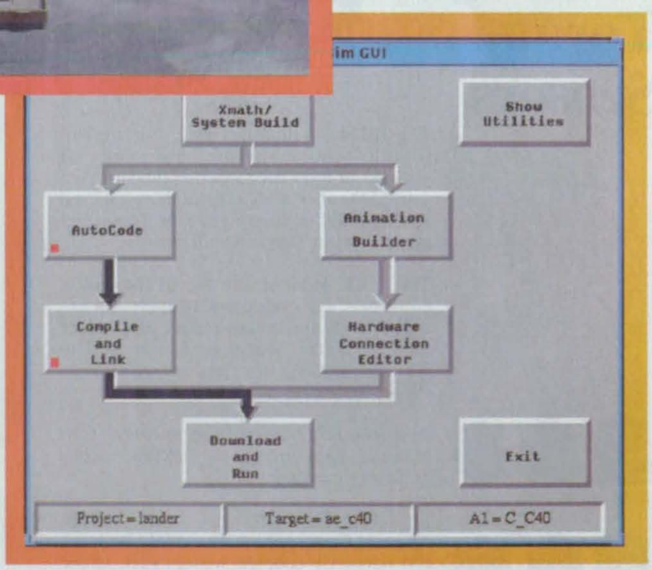

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mid coding scheme also incorporates a context-based arithmetic code that compresses the difference and error terms. The figure illustrates the sequence of reconstructed images obtained by applying the modified mean-pyramid coding scheme to an image of an oilfield.

This work was done by Kar-Ming Cheung and Richard Romer of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 21*** *on the TSP Request Card.*
NPO-18890

Algorithm for a Self-Growing Neural Network

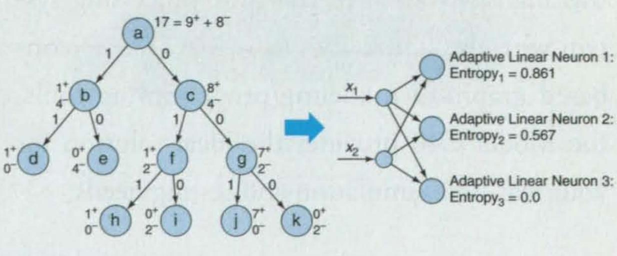
Either a crisp or a fuzzy measure on entropy can be used.

Lewis Research Center, Cleveland, Ohio

The CID3 algorithm simulates a self-growing neural network. It constructs decision trees equivalent to the hidden layers of the neural network (see figure). The algorithm is so named ("CID3" is short for Continuous ID3) because it is based on the ID3 algorithm, which dynamically generates a decision tree while minimizing the entropy of information. [The entropy of a piece of information, x, is given by $-p(x)\log_2 p(x)$, where $p(x)$ denotes the probability or frequency of occurrence of x.] The CID3 algorithm generates a feedforward neural network by use of either a crisp or a fuzzy measure of entropy.

A description of ID3 is prerequisite to a description of CID3. ID3 generates decision rules from a set of training examples. Each example is represented by a list of features. In the training process, classes to which the input data belong must be known. The idea is to find the minimum number of original features that suffice to determine these class memberships. ID3 uses information theory to select features that maximize the information gain in the sense that they maximize the decrease in entropy.

Inasmuch as the number of new nodes added to a decision tree depends on the number of values that a selected feature can take on, the ID3 algorithm requires features to have discrete values. The decision tree thus generated is then described in terms of hierarchical decision rules that must be



$$\text{Entropy}_1 = -\tfrac{1}{17}[(1 \times \log_2\tfrac{1}{5} + 4 \times \log_2\tfrac{4}{5}) + (4 \times \log_2\tfrac{4}{12} + 8 \times \log_2\tfrac{8}{12})] = 0.861 \text{ bit}$$

$$\text{Entropy}_2 = -\tfrac{1}{17}[(0+0) + (0+0) + (1 \times \log_2\tfrac{1}{3} + 2 \times \log_2\tfrac{2}{3}) + (7 \times \log_2\tfrac{7}{9} + 2 \times \log_2\tfrac{2}{9})] = 0.567 \text{ bit}$$

$$\text{Entropy}_3 = -\tfrac{1}{17}[(0+0) + (0+0) + (0+0)] = 0.0 \text{ bit}$$

A **Three-Node Hidden Layer** of a neural network is generated from a decision tree, in the CID3 algorithm, by use of mathematical constructs called "adaptive linear neurons."

used in the order specified by the tree structure. The condition part of a decision rule consists of a number of feature tests linked by AND/OR logical operators. The disadvantage of a feature test is that correlations between features are ignored. ID3 considers only the degree to which each individual feature is significant for classification of training examples.

In the formulation of CID3, ID3 was modified to operate on continuous data and to search for weight vectors that minimize an entropy measure. This measure can be based on either the crisp entropy (the conventional information entropy defined above) or a fuzzy entropy. The fuzzy entropy measure is a modified entropy, derived from fuzzy-logic theory, that accounts for degrees or probabilities of membership in various classes.

The CID3 algorithm comprises the following major steps:

1. For a given problem with N training examples, start with a random initial weight vector, W_0.
2. Using a learning-rule equation, a description of which would greatly exceed the space available for this article, search for a hyperplane in weight-vector space that minimizes the applicable crisp or fuzzy entropy function at a given level of the decision tree or layer of the neural network.
3. If the minimized entropy is not zero, but is smaller than the previous value, add a node to the current layer of the neural network and return to step 2. Otherwise, go to step 4.
4. If the hidden layer consists of more than one node, generate a new layer that utilizes inputs from both the original training data and the outputs from all previously generalized layers, and go to step 2. If the hidden layer consists of only one node, then the problem is reduced to a linearly separable one; stop.

This work was done by Krzysztof J. Cios of the University of Toledo for **Lewis Research Center.** *For further information,* ***write in 78*** *on the TSP Request Card.* *LEW-15931*

Software for Multivariate Bayesian Classification

This program can be embedded in another program or run by itself.

Ames Research Center, Moffett Field, California

PHD is a general-purpose classifier computer program. Originally part of another program, PHD has been extracted and made available for wider use.

"Classifier" in this context denotes a program that accepts data in the form of vectors and assigns a class label to each vector. Typically, a classifier is trained to recognize a set of classes by (a) presenting it with training data in the form of a set of vectors to which the correct labels have been attached, then (b) running a "learning" procedure to characterize the classes. Thereafter, when presented with new, unlabeled vectors, the classifier is required to determine the class to which each vector most likely belongs, along with a measure of confidence in the correctness of the classification of each vector.

PHD was constructed according to the concept of Bayesian inference, a mathematically optimal family of algorithms for classification that has long been a fundamental technique for classification of patterns. PHD uses Bayesian methods to classify vectors of real numbers, based on a combination of statistical techniques that include multivariate density estimation, Parzen density kernels, and the EM (Expectation Maximization) algorithm. By means of a simple graphical interface, the user can train the classifier to recognize two or more classes of data and then use it to identify new data.

The classifier is trained to create a statistical model, known as a "mixture density," for each of several classes of training data. During training, in order to model the training data for a given class, the program searches for a maximum-likelihood (best-fitting) density estimate constructed of one or more multivariate Gaussian kernels. Overfitting (failing to distinguish low-probability noise from higher probability data) is avoided by applying a minimum-description-length criterion to determine how many Gaussian kernels are justifiable in representing the training data. Whereas traditional pattern classification applies a discriminant function to distinguish each class from the others, PHD models each class separately. Thus, outliers that do not belong to any of the known classes can usually be spotted and labeled as "unidentified."

After finding densities for each of the training classes, PHD is ready to assign a class to an unlabeled vector by finding the highest likelihood for that vector from among the known class distributions. If the vector does not belong to any of the training classes, that fact will be reflected in the low confidence measure of its classification; thus, PHD is useful in a task that requires recognition of data that do not fit in any of the known classes.

PHD is written in ANSI C for Unix systems and is optimized for online classification applications. It can be embedded in another program, or it can run by itself using the simple graphical-user-interface. Online help files make the program easy to use.

This work was done by Ronald Saul and Philip Laird of **Ames Research Center** *and Robert Shelton of Johnson Space Center. For further information,* ***write in 60*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center; (415) 604-5104. Refer to ARC-13383.

Fast Parallel Computation of Multibody Dynamics

Processors and computation time are utilized efficiently.

NASA's Jet Propulsion Laboratory, Pasadena, California

The constraint-force algorithm is a fast, efficient, parallel-computation algorithm for solving the forward dynamics problem (given the control forces, compute the motions) of a multibody system like a robot arm or a vehicle. This is the first known algorithm to solve the problem in a minimum time proportional to log(N) by use of an optimal number of processors proportional to N, where N is the number of dynamical degrees of freedom: in this sense, the constraint-force algorithm is both a time-optimal and a processor-optimal parallel-processing algorithm.

Fast algorithms and computers have been sought for use in telerobotic and other control systems. In many of these systems, there is a need for faster-than-real-time simulation of multibody dynamics. Fast serial algorithms with processing times proportional to N have been developed, but even the fastest serial algorithm does not exhibit the requisite computational efficiency, and further improvements in the efficiencies of serial algorithms seem unlikely.

Heretofore, in the development of a typical parallel-processing algorithm, it has been customary to first develop an algorithm for fast serial computation, then attempt to increase the computational efficiency through parallelization. A different approach was followed in the case of the constraint-force algorithm: From the outset, it was developed for efficient parallel computation.

The complexity of the underlying mathematics precludes a detailed description of the algorithm in this article. From the perspective of physics, a given algorithm for multibody dynamics can be classified on the basis of, and can be considered to originate from, its force-decomposition strategy. From the perspective of mathematics, the algorithm can be classified on the basis of that factorization of the mass matrix of the dynamical system that corresponds to the specific force-decomposition strategy. The constraint-force algorithm is accordingly so named because it is

Version	Time (in ms)	Speed	
		Absolute	Relative
Serial	481	1.00	-
N-Parallel	87	5.53	5.53
2N-Parallel	69	6.97	1.26
3N-Parallel	55	8.75	1.25

Significant Speedups Were Achieved in a test computation by use of three different parallel versions of the constraint-force algorithm.

based on a novel decomposition of interbody forces that leads to an explicit computation of constraint forces.

Researchers had previously often argued that because constraint forces are nonworking forces, one should avoid calculating them for the sake of computational efficiency. Although this argument is valid for serial computation, it does not necessarily apply to parallel computation. In this case, the force-decomposition strategy leads to a new factorization of the mass matrix and this factorization, in turn, results in the efficient constraint-force algorithm.

A salient feature of the constraint-force algorithm is that while it is less efficient than other algorithms for serial computation, it is strictly efficient for parallel computation. In addition to its theoretical significance, this algorithm is highly practical and can be efficiently implemented on a variety of commercially available computers that feature multiple-instruction/multiple-data parallel architectures. In a test, the constraint-force algorithm was successfully implemented on a 32-node hypercube computer in which each node contains an 80386 microprocessor, an 80387 arithmetic coprocessor, and 4 MB of random-access memory. The performances of several different versions of the algorithm (a serial version and parallel versions with three different levels of parallelism) were compared with respect to an $N = 8$ test case (see table). The results of the test confirmed expectations that the constraint-force algorithm exhibits a high degree of parallelism in computation with minimum communication and synchronization requirements.

This work was done by Amir Fijany of Caltech and Gregory L. Kwan and Nader Bagherzadeh of the University of California at Irvine for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 31*** *on the TSP Request Card. NPO-19340*

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSPs) when a Request Card number is cited; otherwise they are available from the NASA Center for AeroSpace Information.

Physical Sciences

Thermal Conductance of Gold Contacts at Liquid-Helium Temperatures

A report describes a study of the thermal conductance of gold-plated copper, aluminum, brass, and stainless-steel contacts at temperatures from 1.6 to 4.2 K under applied forces of 22 to 670 N. It was found that the thermal conductance improved greatly as the result of gold-plating, except for the stainless-steel samples.

This work was done by Peter Kittel and Louis J. Salerno of **Ames Research Center** *and Alan L. Spivak of Trans-Bay Electronics. To obtain a copy of the report, "Thermal Conductance of Gold-Plated Metallic Contacts At Liquid Helium Temperatures,"* ***write in 23*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center; (415) 604-5104. Refer to ARC-13178.

Basis and Application of the CARES/LIFE Computer Program

A report discusses the physical and mathematical basis of the Ceramics Analysis and Reliability Evaluation of Structures LIFE prediction (CARES/LIFE) computer program, which was described in "Program for Evaluation of Reliability of Ceramic Parts" (LEW-16018) elsewhere in this issue. As explained in more detail in that article and in the report, this software calculates the time-dependent reliability (probability of failure as a function of time in service) of a monolithic ceramic component subjected to thermomechanical and/or proof-test loading. The report explains the basic equations implemented in CARES/LIFE to mathematically model the various phenomena involved in the failures of ceramic components: CARES/LIFE accounts for subcritical crack growth by use of a power law, the Paris law, or the Walker equation.

This work was done by Noel N. Nemeth, Lesley A. Janosik, and John P. Gyekenyesi of **Lewis Research Center** *and Lynn M. Powers of Cleveland State University. To obtain a copy of the report, "Durability Evaluation of Ceramic Components Using CARES/LIFE,"* ***write in 48*** *on the TSP Request Card.*
LEW-16207

Mechanics

Non-Newtonian Effects in Viscous Flows

A report presents a theoretical study that addresses the persistent problem of explaining the random aspects of the flows of real fluids in terms of the classical governing equations. A review of the classical mathematical formalism of fluid dynamics leads to the conclusion that some of the physically unrealistic aspects of classically computed flows (for example, infinite times of approaching equilibria, and fully deterministic solutions of the Navier-Stokes equations) can be removed by relaxing the Lipschitz condition, which is a requirement that the derivatives of the solutions of the differential equations of flow be bounded. (The Lipschitz condition guarantees the uniqueness of the solution under fixed initial conditions, whereas what is sought here is the non-uniqueness characteristic of real, partly random flows.)

This work was done by Michail Zak of Caltech and Ronald E. Meyers of the U. S. Army Research Laboratory for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Non-Newtonian Effects in Viscous Flows,"* ***write in 22*** *on the TSP Request Card. NPO-19728*

Theory of Controlling Spacecraft Motion With Pulsed Thrusters

A report presents a new class of flight-control laws for making a spacecraft follow a desired trajectory by use of pulsed thrusters during such maneuvers as automated rendezvous on orbit and soft landing on a planet. The guidance problem is solved with an extension of robust nonlinear control theory, resulting in algorithms that determine the duration and frequency of thruster firings from estimates of spacecraft position and velocity. These algorithms incorporate a complete nonlinear dynamical model of the spacecraft motion, and enable analytical characterization of transient-error behavior, limit-cycle dead-band region, and the domain of possible terminal states. Although the emphasis in the report is on guidance, it is ultimately shown that the same techniques are also useful for attitude control and station keeping. A realistic application is illustrated via computer simulation of a soft landing, on Mars, of a robotic spacecraft equipped with an inertial-guidance system.

This work was done by Sam W. Thurman of Caltech and Henryk Flashner of the University of Southern California for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "A New Pulse-Modulation Technique for Guidance and Control of Automated Spacecraft,"* ***write in 20*** *on the TSP Request Card. NPO-19695*

Machinery/Automation

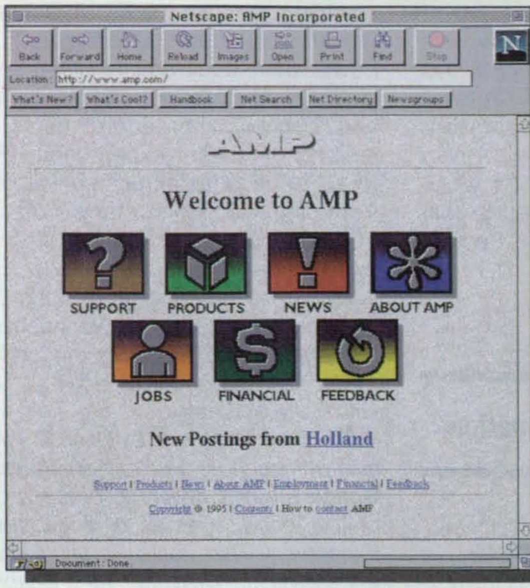
Experimental Study of Rotating Unbalanced-Mass Actuators

A report discusses the theory of rotating unbalanced-mass (RUM) actuators and describes experiments to test the concept of using RUM actuators for mechanical scanning of scientific instruments in linear, circular, or raster patterns. This concept and some aspects of the design and operation of RUM actuators have been described in several previous articles in *NASA Tech Briefs*.

Previous calculations had shown that scanning by use of RUM actuators should consume significantly less power than does scanning by use of gimbal actuators in both gravitational and nongravitational environments. The results of these experiments were found to be in fair agreement with data from simplified computer simulations of the experiments. The results verify expectation of reduced power consumption; depending on the particular test configuration, the power needed to scan with gimbal actuators ranged from 17 to 494 times that needed to scan with RUM actuators.

This work was done by Dean C. Alhorn and Michael E. Polites of **Marshall Space Flight Center**. *To obtain a copy of the report, "Results of a Laboratory Experiment That Tests Rotating Unbalanced-Mass Devices for Scanning Gimbaled Payloads and Free-Flying Spacecraft,"* ***write in 61*** *on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-28994.



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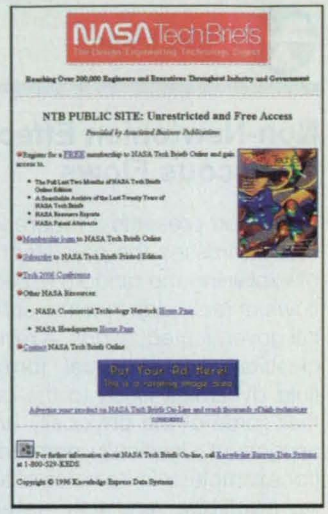

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New Literature

A 70-page handbook of **fittings, tubing, and valves** is available from Cole-Parmer Instrument, Vernon Hills, IL. New products include polycarbonate and polysulfone quick-disconnect fittings and platinum-cured silicone tubing.

For More Information Write In No. 740

Materials for **noise, vibration, shock, and motion control** are described in a product guide from E-A-R Specialty Composites, Indianapolis, IN. Featured are absorbing foams, barrier composites, isolation materials, grommets, and mounts.

For More Information Write In No. 741

National Instruments, Austin, TX, has released its 1996 catalog of **computer-based instrumentation products**, including software and hardware for test, measurement, and industrial communication. The 624-page catalog features sections on data acquisition and industrial automation.

For More Information Write In No. 742

A 12-page brochure of **miniature and sub-miniature position transducers** is available from SpaceAge Control, Palmdale, CA. The transducers are used in the automotive, aerospace, and automation fields for test and development, industrial control, and OEM applications.

For More Information Write In No. 743

Axon Instruments, Foster City, CA, has released a 180-page 1996 product catalog of **scientific instruments**, including data acquisition and analysis hardware and software, microelectrode amplifiers, cellular imaging products, and simulation software.

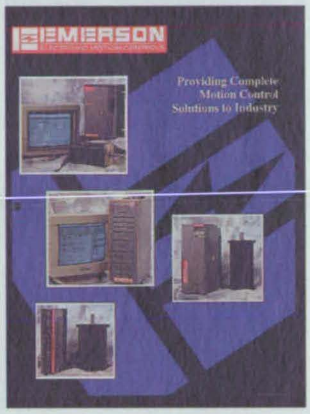
For More Information Write In No. 744

Molded and stamped rubber products are described in a 20-page brochure from Syntex Rubber Corp., Bridgeport, CT. Included are grommets, O-rings, rubber tips, shock mounts, stoppers, suction cups, bumpers, and capacitor boots.

For More Information Write In No. 745

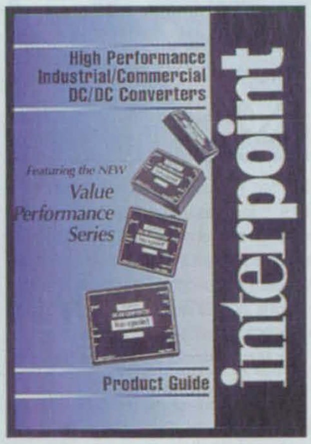
Hamilton Precision Metals, Lancaster, PA, offers a 24-page technical brochure describing precision tolerance **metal alloy strip and foil**, which is available in thicknesses from 0.050" to 0.000060", and widths to 15". Applications include medical instrumentation, computers, electronics, and automotive.

For More Information Write In No. 746



A six-page brochure from Emerson Electronic Motion Controls, Chanhassen, MN, describes **motion control devices**, including brushless positioning servo drives, digital and analog servo drives, and multi-axis controllers. Related system software also is featured.

For More Information Write In No. 747



Interpoint Corp., Redmond, WA, has released a product guide describing 35 new **DC/DC power conversion products** for industrial, commercial, and military applications. The new VP Series features output power ranges from 6 to 45 watts in single, dual, and triple output configurations.

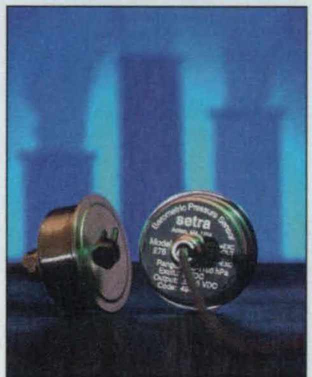
For More Information Write In No. 748

New on the Market

Product of the Month

FieldWorks, Eden Prairie, MN, has introduced the FW7600 Field WorkStation™ **rugged laptop computer**, which features 100 MHz 486 or Pentium processors. The computer operates on AC, battery, or 12V DC input power and includes multiple slots: one PCMCIA slot and three ISA slots for the standard model; one PCMCIA plus three ISA or three PCI slots (or any combination of the two) for the Pentium model. It weighs 14.7 pounds, and features a sealed Field MousePad pointing/drawing device, integral CD-ROM drive, and a one-piece chassis that meets military standards for shock and vibration.

For More Information Write In No. 700



The Model 276 **pressure transducer** from Setra Systems, Acton, MA, features a variable-capacitance sensor, which provides high thermal expansion coefficient and low mechanical hysteresis. The device is available with 0.1 or 0.2% accuracy and a 1/8" NPT pressure connection for use in industrial and aerospace applications.

For More Information Write In No. 701

Meritec, Painesville, OH, has introduced MSI™ **terminated connectors** for cable routing requirements in LCDs and printed circuit boards. The cable assembly is designed for critical mechanical applications and is available with 31 or 41 connectors, with or without pull-tabs.

For More Information Write In No. 702

The K4 Series of **sealed toggle switches** from Otto Controls, Carpentersville, IL, feature front panel snap-in mounting and illuminated function indication. The single- and double-pole switches are available in two- and three-position circuit combinations for use in severe conditions in equipment, industrial control, and marine applications.

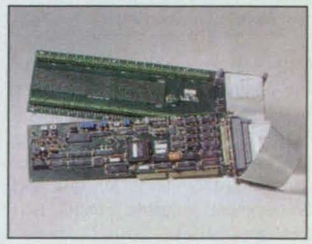
For More Information Write In No. 705

Parity Systems, Los Gatos, CA, offers the EtherStor™ **intelligent storage controller**, which increases network storage capacity without adding a workstation or server. It provides direct attachment of SCSI storage devices to any Ethernet network that uses UNIX or Netware protocols and supports up to 56 Gb of disk space or seven CD-ROM drives.

For More Information Write In No. 704

The HLE80 **linear positioning drive** from Parker Hannifin Corp., Daedal Division, Harrison City, PA, is a low-mass cartridge positioned within an extruded aluminum profile. The modular component is available with a range of stepper and servo motors and allows configuration of multi-axis systems for automation applications.

For More Information Write In No. 703



Omega Engineering, Stamford, CT, offers the DAS-1800 Series **plug-in boards** for high-speed data acquisition in Windows or DOS on IBM-compatible computers. They feature 64 single-ended inputs of 32 differential inputs at up to 333 ksamples/second or 100 ksamples/second. The boards plug into a 16-bit AT-style slot.

For More Information Write In No. 706

New on the Market

Methode Electronics Interconnect Products Division, Rolling Meadows, IL, has introduced a 1.0 mm **surface mount header and connector system**, which provides maximum space utilization for high-density circuits. It is available with 4 to 60 circuits and features industry-standard platings.

For More Information Write In No. 707

ICEBrite™ VGA electroluminescent **flat panel displays** from Planar Systems, Beaverton, OR, are available in 10.4", 8.1", and 6.4" diagonal sizes. They feature 640 x 480-pixel formats and produce a high-contrast visual image tolerant to ambient light. The displays feature response time of less than 1 millisecond, a viewing angle of more than 160°, and a display life of more than 120,000 hours.

For More Information Write In No. 708

Monarch Instrument, Amherst, NH, has introduced Data-Chart® 3000, a one- to six-analog input series of **paperless recorders/data acquisition systems** for process monitoring, instrumentation, and recording. The systems feature up to 12 channels of information and touchscreen control. Data is stored simultaneously in an internal buffer and either a PCMCIA card or 3.5-inch floppy disk.

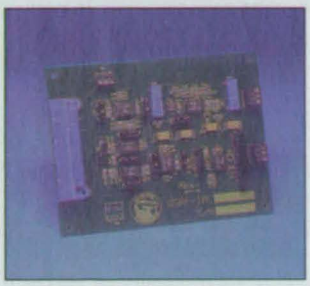
For More Information Write In No. 709

Exergen Corp., Watertown, MA, has introduced the IRt/c.3X **non-contact temperature sensor** with a sensing range of -40 to 650° C and a 17° field of view. The sensor fits most temperature control systems and includes a built-in air purge for operation in rugged environments.

For More Information Write In No. 711

A line of ultraviolet, x-ray, and particle **diamond radiation detectors** is available from Alameda Applied Sciences Corp., San Leandro, CA. They use bulk photoconductivity to provide <1 ns rise-time measurements of photons, electrons, ions, and neutrons. They are available in SMA, ultraminiature, and Type N mounts.

For More Information Write In No. 710



The GSAF-10 Gold Series **analog low-pass filter** from Alligator Technologies, Costa Mesa, CA, is installed between sensors and an A/D converter board in data acquisition systems. The fixed-frequency board provides one differential-input channel and can be mounted on the benchtop or plugged into a 21-channel backpanel.

For More Information Write In No. 712

Life Sciences, St. Petersburg, FL, offers the Enviroscreen, a computer-linked **optoelectronic analyzer**, which is a portable, spectrograph-based instrument for detection and measurement of metals, volatile organic compounds, and other organic and inorganic substances. It measures absorbance, reflectance, and fluorescence over the 200-2000 nm range.

For More Information Write In No. 713

Hewlett-Packard, Palo Alto, CA, has introduced a two-channel **digital-storage oscilloscope** that features a 1-gigasample/second sample rate and 500 MHz bandwidth. It supplies automatic measurements of frequency, voltage, pulse width, and rise time for engineers and technicians working with mixed-signal circuits.

For More Information Write In No. 714

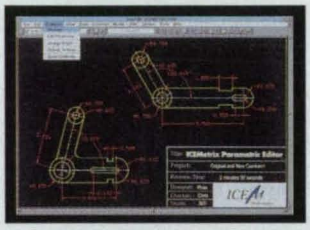
The Model APP-100APR **computer-controlled automated pressure regulator** from Advanced Pressure Products, Ithaca, NY, controls gas pressure remotely without operator assistance. For use in laboratories and process control applications, the regulator controls system pressure automatically from a computer or other controller.

For More Information Write In No. 715

New on Disk

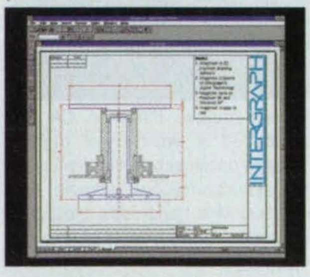
Ricoh Corp., Software Research Center, San Jose, CA, has introduced Windows version 5.0 of DesignBase™ **solid and surface modeling software**, which provides program development, on-line documentation, a graphical developer's interface, and 2000 different functions. Designs can be created and modified directly or through dimensional parameters.

For More Information Write In No. 720



ICEMetrix **parametric AutoCAD editing software** from ICEM Technologies, Division of Control Data Systems, Arden Hills, MN, provides dimension-driven geometric editing of any 2D AutoCAD drawing. It automatically recreates a drawing whenever dimensions are changed and runs entirely in AutoCAD, requiring no special drawing preparation. The software costs $487 and runs with AutoCAD R12 and 13 in DOS, Windows, or Windows NT.

For More Information Write In No. 721

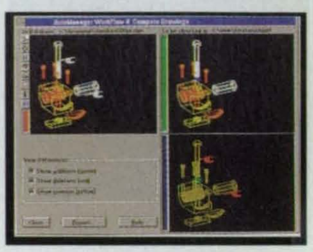


Intergraph, Huntsville, AL, has introduced Imagineer Technical™, a **2D drawing and concept design tool** for Windows that allows engineers, designers, scientists, and inventors to perform 2D sketching, concept design, and project review. It features 32-bit drawing power, compatibility with AutoCAD and MicroStation, and allows linking/embedding of drawings in word processing, spreadsheet, and presentation files. The program requires no formal training and is available at an introductory price of $279.

For More Information Write In No. 729

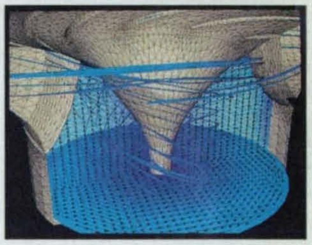
Cadra® version 10 **CAD/CAM/CAE tools** from Adra Systems, Chelmsford, MA, integrates separate modules for design drafting, numerical control, solids modeling, electrical control, and power systems design. It is compatible with Windows, DOS, and UNIX platforms, and can take data created in any form from a translator and manipulate it as native data.

For More Information Write In No. 723



Cyco International, Atlanta, GA, offers AutoManager WorkFlow **document management software** for drawings, spreadsheets, memos, engineering change orders, and scanned images. Documents and related data can be tracked, retrieved, marked-up, and verified within a workgroup or across an enterprise. It is available for DOS or Windows, works with various CAD programs, and costs $799 per license.

For More Information Write In No. 722



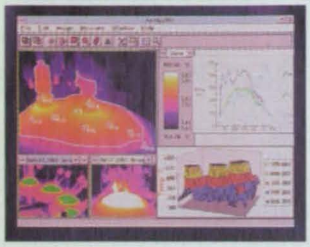
Computational Engineering International, Research Triangle Park, NC, has released EnSight™ 5.5 **engineering postprocessing software**, which postprocesses and animates up to eight datasets simultaneously. In addition to standard planar clipping, the program provides clipping against quadric surfaces such as cylinders and cones. Designed for computational engineers, it can postprocess data from most commercial analysis packages. A perpetual license starts at $8000.

For More Information Write In No. 731

Compunix, Southfield, MI, has released IGES/STL **rapid prototyping enabling translation software**, which provides bidirectional translation between IGES and STL data formats. The program improves data translation quality by repairing gaps between adjoining surfaces, warped surfaces, and incorrect surface normals, allowing STL files to be used with rapid prototyping machines. It is available in Windows or DOS formats.

For More Information Write in No. 724

New on Disk



AnalyzIR+ Windows-compatible **image analysis and report generation software** from FLIR Systems, Portland, OR, allows users to read popular file formats and legacy files captured from infrared cameras. The program can track images and temperatures over time and uses spatial calibration to determine the length and area of objects. The cost is $3000.

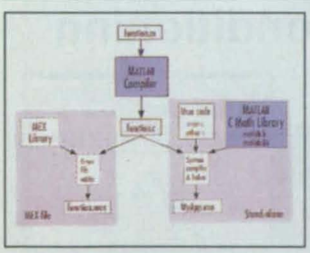
For More Information Write In No. 725

Industrial Systems, Bothell, WA, has released UNIX version 3.2 of CIM/21® **process information management software**, which features display and analysis capabilities. Users can graphically monitor system performance, perform backups, and manage scanning and history subsystems and system security. Time series data such as temperatures, flows, and pressures can be viewed in batch context.

For More Information Write In No. 726

Eaglei **virtual systems integration software** from Eagle Design Automation, Beaverton, OR, was designed for PC-based Windows NT embedded system development and consists of two components: the Virtual Product Console (VPC) and the Virtual Software Processor (VSP). VSPs are software models of popular microprocessors for use with the VPC, which links the microprocessor descriptions with application software code. Prices start at $40,000.

For More Information Write In No. 728

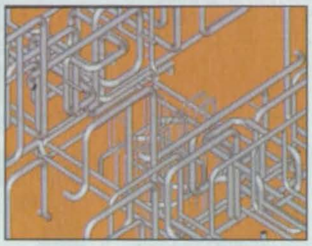


The MathWorks, Natick, MA, has introduced MATLAB Compiler and MATLAB C Math Library **technical computing modules.** MATLAB Compiler allows users to automate the conversion of MATLAB code to portable ANSI standard C or MATLAB-callable executable functions; MATLAB C Math Library makes MATLAB math functions accessible as a cross-platform foundation for standalone applications. Both programs are available for Windows and UNIX platforms. Compiler prices start at $895; Library prices start at $595.

For More Information Write In No. 727

ENVI™ **image processing software** from Research Systems, Boulder, CO, was designed for scientists who analyze and visualize remote sensing data. Featuring array-based image math and an annotation package, it allows users to read, display, analyze, and output any spaceborne or aircraft digital imagery. Ground-based and laboratory spectral measurements also can be imported, manipulated, and analyzed. It operates on UNIX and Windows platforms on a Macintosh or PC.

For More Information Write In No. 730



Algor, Pittsburgh, PA, has introduced Integrated Plant Package (IPP) software for designing, engineering, and analyzing **piping systems, pressure vessels, and heat exchangers.** The package consists of three tools: Pipepak piping system structural analysis program; FE/Pipe finite-element analysis program; and BOS/Fluids, which simulates how fluid phenomena affect piping systems.

For More Information Write In No. 732

MANTA 4.0 **visual product data management software** from B.A. Intelligence Networks, Southfield, MI, is an upgrade that supports design and engineering through a product life cycle via visual presentation of product-related data. Users can track, control, and manage tasks and data involved in product design.

For More Information Write In No. 733

ESM Software, Hamilton, OH, has released MAPP **engineering materials property database software** that interfaces with the ASM International® Mat.DB® engineering materials properties databases. The program allows access to mechanical, physical, and chemical properties of more than 6000 commercial alloys and polymers from a Windows or Macintosh platform. The cost is $495.

For More Information Write In No. 734

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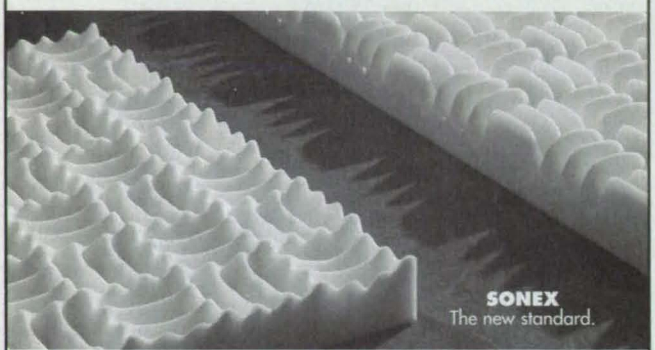

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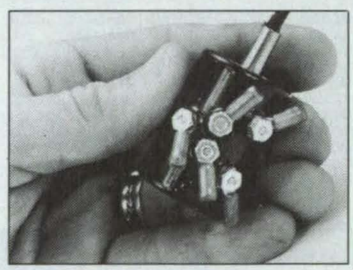

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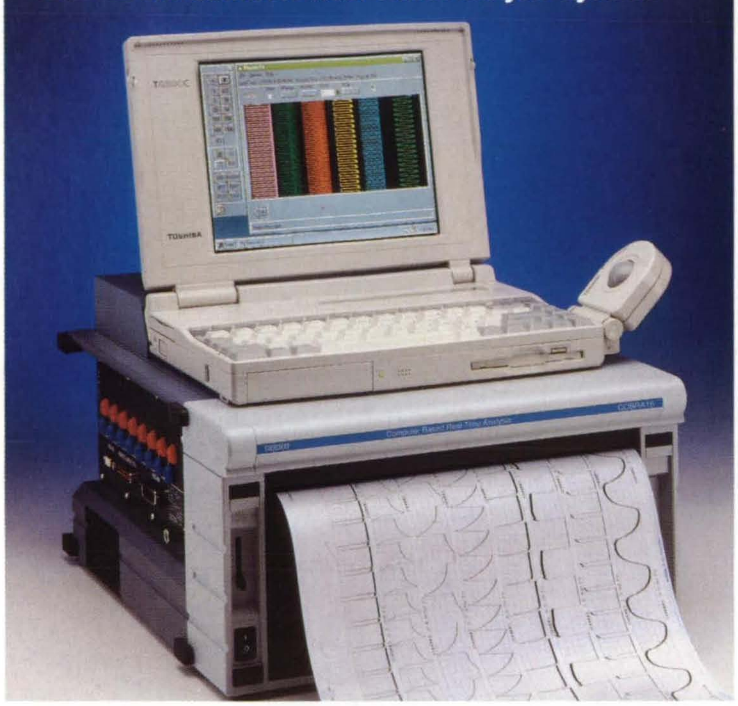
GOULD
Instrument Systems

New Gould COBRA16 Real-Time Analysis System



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